GRAPHICAL METHODS

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FOR

SCHOOLS, COLLEGES, STATISTICIANS, ENGINEERS AND EXECUTIVES

BY

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PREFACE

Up to the year 1910 there was not a book in the English language treating of the art of graphical representation.

A book on the Construction of Graphical Charts appeared in 1910 and one on Graphic Methods in 1914 but neither one treated the subject from the same standpoint. The first book was mathematical and the second contained no mathematics at all. It required the training of an engineer to understand the first while the principles contained in the second could be comprehended by the average man of business.

The author believes there is a demand for a book embracing both the fields mentioned above, but not entering the field of maps, orthographic projection or Graphical Statics. The matter contained in such a book should be presented in such a way as to be readily understood by anyone with a common school education or higher and he or she ought to be able to construct or interpret the charts described therein.

With this thought in mind the following pages are offered in hope that some of them will appeal to some men but not all of them to all men.

W. C. Marshall.

New York,
August, 1921.

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GRAPHICAL METHODS

CHAPTER I

INTRODUCTORY

Various methods ordinarily employed for solution of mathematical problems are well known to all familiar with arithmetic, algebra and geometry.

There is, however, a method of answering a certain class of questions and representing certain results by a direct appeal to the eye which is extremely simple, very effective and in some cases superior to every other mode. This method involves the drawing of a few lines, straight or curved as the problem demands. The use of simple graphic tables for computation is encountered in antiquity and the middle ages.

The graphical solution of spherical triangles was in vogue in the time of Hipparchus (B. C. 161–127) and in the 17th century by W. Oughtred.

Edmund Wingates' "Construction and Use of the Line of Proportion," London, 1628, described a double scale upon which numbers are indicated by spaces on one side of a straight line and the cones ponding logarithms by spaces on the other side of the line. More systematic use of this idea was made by Pouchet in 1795.

In 1842 Leon Lalanne, the Parisian engineer, published his "Anamorphose Logarithmique" in which he explains the first principles of nomography. Advances were made along this line by J. Masson of the University of Ghent in 1884 and E. A. Lallemand in 1886. The real creator of nomography was Maurice d' Ocagne of the École Polytechnique, Paris, whose first researches appeared in 1891. His "Traite de Nomographie" came out in 1899.

In 1910 Prof. John B. Peddle published a book on the construction of graphical charts in which the subject is treated from a

mathematical standpoint. The alignment diagrams and methods of Prof. d' Ocagne are treated at some length.

In 1914 Willard C. Brinton published the first book on graphic methods which could be used by the average business man not having had an engineering or college training. This treats of statistics, organization and routing with very little concerning computation.

Prof. Joseph Lipka published in 1918 a book treating of graphical and mechanical computation, embodying the courses given by him at the Massachusetts Institute of Technology. This treats of the subject from a mathematical standpoint.

Many articles describing the use of diagrams as well as their construction have appeared from time to time in engineering and technical periodicals. The present extensive use of diagrams for shortening the labor of solving mathematical formulas may be accepted as sufficient proof of the general recognition among engineers of the value of graphical methods.

Graphical methods comprise all those methods of representing the relations of objects or facts by means of the relations between the lines of a diagram. All devices for representing by geometrical figures the numerical data which result from the quantitative investigation of phenomena are included under this title. Graphical methods of representing forces, motions etc., by lines have been in common use among mathematiciens and engineers for many years and are known by the name of graphical statics. Similarly any physical quantities such as temperatures, atmospheric pressures or barometric heights, electrical potentials, etc., may be represented by straight lines. Graphical methods are employed to a large extent in physical investigations as aids to calculation and for the purpose of exhibiting the nature of the law of variation of various phenomena. The principal use of these methods is to show the mutual variation of two quantities, as evidenced by (1) the conveying of information, as when parallel lines of different lengths are exhibited which are proportional to the population of different countries or to the population of one country at equal periods of time and (2) to aid numerical or logical calculations as when a curve is drawn through points whose coordinates represent the population of a country at successive decadal intervals: and this curve is used to ascertain the population at other dates. There are three classes of graphical methods: (1) those which make no use of the

continuity of space except to show that the extremities of lines are connected (graphs), (2) those which use only the projective properties of space such as drawings and maps and (3) those which use only the metrical properties of space and produce diagrams intended to be measured. To this class belong graphical statics.

Any quantity susceptible of mensuration can be graphically represented by a straight line, the length of the line corresponding to the value of the quantity. Addition, subtraction, multiplication and division of pure numbers are easily carried out graphically by means of lines. The application of this is found in the slide rule used by engineers for computing.

Graphical methods have great value in the interpretation of tables and solution of formulas because of the ease of drawing a line, the cheapness of paper and pencils and the skillful judgment of the human eye. The representation of quantities on paper is a convenient way of placing them before the eye, of comparing them, of handling them. The simplest application is met with in the representation of tabular data such as that met with in statistics.

The graphical methods of discussing experimental data are of great convenience and importance when the problem under investigation is to determine the law or fundamental relationship between two quantities. This type of problem arises frequently in technical and scientific investigations. The geometrical solution of arithmetical and algebraical problems is usually termed graphical analysis.

Graphical methods are inferior to numerical in accuracy. Ease and rapidity are essential when we want to compare many sets of facts together because if the mind is long delayed in taking in the facts of one set it loses count of the others. The function of graphical representation is to facilitate comparison. A table of statistics represents in one vertical column or row of figures a series of quantities of one kind and in a parallel row or column a series of quantities of another kind each horizontal or vertical pair standing in some definite relation to one another. These classified facts may also be expressed graphically, thereby appealing to the eye as well as the intellect and accomplishing a two fold purpose. By tabulation we reduce facts to a logical order. By graphics we add to their value.

A *graph* is a pictorial representation or statement of a series

of values all drawn to scale. It gives a mental picture of the results of statistical examination in one case while in another it enables calculations to be made by drawing straight lines or it indicates a change in quantity together with the rate of that change. A graph then is a picture representing some happenings and so designed as to bring out all points of significance in connection with those happenings. When the curve has been plotted delineating these happenings a general inspection of it shows the essential character of the table or formula from which it was derived. For example if the world's production of tobacco over a number of years be plotted, a poor yield is represented by a depression, a rich one by a peak, a uniform one over several years, by a horizontal line and so on.

Moreover, such graphs permit a convenient comparison of two or more different phenomena and render apparent at first sight similarities or differences which can be made out from tables only after close examination. The full importance and usefulness of graphs can only be appreciated after many applications have been made.

Diagrams do not add anything to the meaning of statistics but when drawn and studied intelligently they bring to view the salient characteristics of groups and series and suggest in what directions investigation is needed. They are generally illustrations of the analysis obtained by reference to tabulated matter. They clarify the latter but do not displace it; in fact their use supplements it and enables conclusions to be formed by a superficial view of it.

Diagrammatic presentation is used in a narrower and less inclusive sense than the expression "graphical methods," primarily for the reason that graphs of various kinds may be used advantageously in connection with averages and other summary expressions. Graphs and pictorial illustrations are generally discussed together but the latter are not only unlikely to be of much use but in advertising and political propaganda are often deliberately misleading though literally correct. For this reason we shall omit the latter except for purposes of criticism. It may be necessary oftentimes to present a pictorial illustration in order to sell an inferior product by means of a highly colored diagram.

They are used many times to enable those to interpret their meaning who are either too lazy to study the tabular matter or not intelligent enough to abstract the matter contained in the

tables. Simplicity and truthfulness should be the aim in graphical presentation. Find the best form of representation to use and seek to fit it to the requirements of the problem as to order of arrangement of details, spacing, size of figure and methods of making emphatic the relations between facts. A skilful writer can often devise statistical diagrams of other kinds which help the visualization of a complex argument. The final test of a diagram's value is its legibility and clearness of meaning. The diagram should carry on its face a sufficient definition of the facts represented.

The psychology of statistical diagrams seems to depend on the difficulty of holding in the mind at one time all the mass of numerical facts contained in a series of statements, and for this reason tables are used. The tables, however, compensate only in part for this fault and it becomes necessary to still further crystallize the facts in diagrams.

The graphical method should rarely be used except:

1. To show the relations of one part of a group to another.
2. To exhibit a series of similar estimates date by date.
3. To compare two or more groups.
4. To compare two or more series.
5. To exhibit three relations which can be geometrically united.

Monsieur Leterrier, professor in the elementary schools of France, believes that the impression produced by a graphical diagram showing historical facts will help to clear up ideas and fix them in the minds of children.

Such historic facts that can be measured (figures of receipts and expenditures, numbers of cannon, soldiers, ships, etc.) can be made concrete rather than abstract by diagrams.

The scholar will understand better the importance of certain details which were only confused in the midst of changes of the past and which arrested his attention with difficulty. The diagram can be used in reviewing and for quizzes. The teacher can request the pupil to justify the rise or fall of a graph at such and such a spot or period of time. As an illustration take the graphs in Fig. 1 showing the increase in domain of the French kings. Here the scales are in square kilometers on the Y-axis and 20-year periods from 987 to 1789 on the X-axis.

"Some scholars with distracted or light minds, not able to follow the teacher in the statement of facts nor draw any conclusions, have become suddenly interested by seeing drawn on

the board a curve which measured the relative importance of each of the facts and at the same time showed the nature of their evolution."

Business executives cannot afford to ignore the merits of graphical representation which have for so long been accepted by the engineer and man of science. They must look behind the

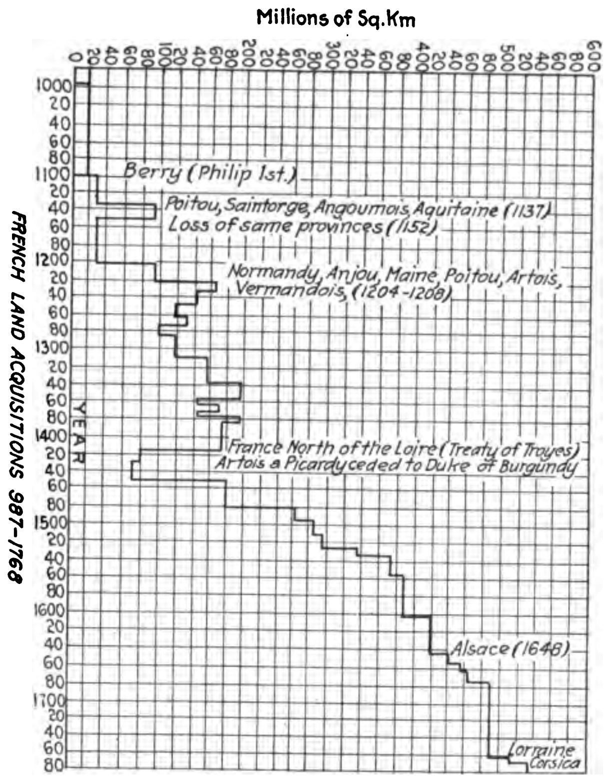


FIG. 1.—French land acquisitions from 987 to 1768.

graphical method and study the conditions leading to the picture along with the picture itself. No business is too small to profit by an examination which shall analyze and scrutinize nor too large to ignore its possibilities. Each business must adjust the graphical methods to its own peculiarities and each diagram must be adjusted to the individual for whom it is prepared or the individual must be educated up to the use and importance of these methods of analysis.

The diagram prepared for an executive will be different from the one designed for the public at large. Graphic presentation is an art and the modern executive cannot give too much attention to its application to his business from the scientific standpoint of management if nothing else.

There has been a growth of no small amount in the past 10 years in the use of graphical methods for all kinds of tabular classification, from newspapers to higher mathematics. How has it come about? In precisely the same way as twitch grass spreads over a lawn underground. One man gets his cue from some diagram he happens to see, tells another one who in turn passes it along and the chain continues to grow. The first man, however, begins to think about the application, he can make, of use in clarifying his reports or simplifying his calculations, and soon has evolved something better than the originator. Sometimes he publishes his discoveries and the general public is benefited, but more often this advance in graphical research remains hidden and of use to a very small group of co-workers.

What we ought to have in every school, college and university in the country is a course covering the use and construction of graphical diagrams together with graphical methods. It should cover all kinds of devices for enabling the eye to quickly grasp the features delineated on paper or board useful in illustrating past, present or future happenings. No efficient management can afford to do without graphical methods in production, planning, cost accounting, organization, purchasing, sales, engineering or store departments.

At the present time there is a total lack of standardization in the form of diagram to use for nearly all classes of representation. This makes it difficult to compare reports of different investigators on the same subject because their diagrams are not constructed alike. If one uses revolutions per minute, the other feet per minute, comparison is very difficult, especially when one uses it on a vertical axis while the other prefers a horizontal scale. There are certain classes of data which are always represented graphically in the same form of diagram. Certain graphical recording instruments use charts of the same form, either circular or ribbon, with records thereon made in the same way. In nearly all of these charts the motion imparted to the paper is obtained by clockwork, one of the units therefore being an element of time, usually the hour. The other unit may be

temperature, pressure, volume or action, but time is common to all and is comparable in all.

The indicator card of a steam or internal-combustion engine has been made in a standard way for many years and comparisons of indicator cards are very easily made on that account. We find diagrams divided into three classes:

1. Those which appeal to all classes of people because they illustrate things of interest to nearly everyone and are simple to understand. In this class are price fluctuations of stocks, food, coal, rainfall, election returns, football games, etc.

2. Those which appeal to executives and engineers, comprising such charts as transportation costs and growths, costs of lighting, wages of employees, organization charts, traction and speed of locomotives, etc.

3. Those which are constructed, understood and used by technically trained engineers and specialists and comprising calculating diagrams. Among these are charts for solubility of CaCl in H_2O,sag of steel tapes, steam boiler tests of coals, torque of electric motors, moments and shear in concrete ships, retaining walls, relation of cut and speed in machine tools, etc.

Engineering periodicals, technical books, newspapers, and textbooks contain an endless variety of charts good and bad, clear and complex, useful and useless, until the layman and often the engineer wonders what they are all about. The word "nomography" means nothing to the average man, I might say the average engineer, but it is of very great importance in graphical chart making. Every technical man should know its possibilities and be able to apply its principles in his line of work. The slide rule was used but little 25 years ago but today every engineer knows how to use one and the principles governing its construction. Engineering handbooks published within 10 years contain many more diagrams than previous to this period, all with the aim of showing certain laws and dependence of one variable on others.

We recognize the value of graphical methods but are lax in teaching them in our schools and adopting them in standard form in our engineering and scientific societies.

OCCUPATIONAL DIVISION

The distribution of graphical methods may in some cases be extremely limited and again be so wide as to embrace all kinds of

tabular analysis and be necessary for properly and quickly understanding the important deductions to be made from the tables.

Roughly speaking there are three classes of diagrams. In the first class are those diagrams used by specialists in scientific lines and comprise such as are given below. In this class will be found nomograms which are known to engineers and mathematicians and not to the average college or technical school graduate. Most of the diagrams of the following classes are simple coordinate or logarithmic diagrams and can be constructed by any high school student with a knowledge of graphic algebra or analytical geometry. A great number of those mentioned in class (1) apply to some special line of work and would be of little interest to persons outside that line. For example, "heat transfer in surface condensers" would be used by power or marine engineers only. A flow sheet in a copper mill would be in the field of metallurgy; airplane propeller curves in the aeronautic field; costs of ploughing in the agricultural engineering branch of automotive engineering; relation of cut and speed in machine tools would belong to the mechanical engineer.

Class 1.—This comprises the following diagrams: solubility of CaCl in H_2O, study of Indian music, weighing machine hysteresis loop, curves for airplane propellers, appraisal of oil wells, efficiency of boilers, accelerometer tests, sag of steel tapes, retaining walls, cam curves, cargo ship calculations, carburetter mixture requirements, steam boiler test of coals, comparison of coal and oil fuel, gear and pinion hardness, speed and resistance of ships, reinforced concrete, heat transfer in surface condensers, costs of railroad ties, costs of ploughing, costs of Scotch pig iron, design of stuffing box glands, draft in steam boilers, torque of electrical motors, steam turbine characteristics, heat bal. tests in auto engineering, gear design, flow sheet in copper mill, gas velocity through poppet valves, weight of water in marine boilers, hardness of babbitt, locomotive heating curves by exhaust steam, relation of depth of cut and speed in machine tools, moments and shear of concrete ships, well spacing in oil lands, efficiency curves of centrifugal pumps, textile engineer organization chart, steam flow in pipes, power plant efficiency, power to swing bridges, power to crank motor, efficiency of airplane propellers, skin friction and resistance of ships, heat calculation charts, acceleration curves, per cent power gained by vacuum.

Class 2.—In the second class will be found diagrams having a general engineering application and comprising the following: progress reports, purchase records, volume of hor-cyl. tanks, accounting operations, manufacturing efficiencies, specific weight, curves for air, area of segments of a circle, speed of vehicles and diameter of wheels, costs of transportation by motor vehicle, costs of gas and electric lighting, weight of flat steel, inches of water per pound, per square inch, trend in truck design, horsepower and cyl. vol. of motors, flow sheets of work in manufactures, graphical control, hardness and temperature of steel, mechanical properties of steel, horsepower of conveyors, lighting distribution, terminal handling of locomotives, horsepower loss in roller bearings, tension in bolts and screws, worm gear characteristics, power tests of machine tools, viscosity of oils, operating data, organization charts, velocity of H_2O in tubes, production records, propeller characteristics, riveted joints, routing of shop work, autographic load diagrams, distribution of temperature in bearings, time curves for steam shovels, traction and speed of locomotives, records of engineering graduates, weight of prime movers, weight of electrical machinery, etc.

Class 3.—In the third class are all diagrams which interest the general public either from a personal or educational standpoint. They show progress or the history of those things which are of financial, political or healthful importance or pertain to sports. This class then comprises such diagrams as compensation of employees, development of aircraft performance in war, automobiles stolen and recovered in Detroit 1916–18, coal produced in the United States, coal consumption for heating homes, costs of living, shifting of labor, mental tests of employees, industrial accidents in iron and steel industry, auto design trends, relation of defective locomotives to accidents, season load curves of electrical stations, Government organization charts, price fluctuations, coal production, automobile production and prices, piecework rate and wage calculations, roads built in the United States, freezing temperature scales,wet and dry bulb temperature charts, horse and mechanical traction, truck operation and efficiency, endurance of human body, food curves and calories, water waste prevention, rainfall, stock market fluctuations, election returns from different states, football game charts, power boat races, etc.

Certain kinds of diagrams have been standardized and are always used in the graphical representations of certain classes of

information. The torque and horsepower curves of gasolene motors, electric motors and steam engines are usually shown on rectangular coordinate charts having the horizontal scale of revolutions per minute and the vertical scale of scale pressures or horsepower. Fluctuation of prices of commodities, stocks and bonds, over various periods. are shown on rectangular coordinate diagrams on which time intervals are measured along the horizontal and price variations along the vertical.

Engineering handbooks have diagrams which graphically aid calculation, their basis being formulas of design, tests of apparatus, operation of factories, railways and machinery, efficiency of machinery, organization of employment, production of goods, tools, etc., handling and transportation of material.

In looking through the handbooks published for the various professions or occupations one finds diagrams pertaining to the particular branch covered by the book and also general diagrams which will assist in the computation of general formulas. Some of the diagrams are as follows:

Civil engineering handbooks contain diagrams on consumption of water, power, tractive resistance, flow of water, areas, railroad operation, stresses, strength of beams and columns, railroad curves, earthworks, weight of concrete construction, strength of steel and concrete, evaporation, volume and per cent of mixtures for roads, filtration and filter beds, sand composition and water storage.

Mechanical engineering handbooks have diagrams in them dealing with costs of machinery and power, efficiency of machines, boilers and coal, flow of water and steam or gas, conversion charts, friction, conveying machinery, heating and ventilating, time and labor, production and design.

Electrical handbooks show diagrams of wiring, motor characteristics, electric railway operation, costs of electrical power and lighting, speed, time and distance, transformer losses, efficiency of motors and generators and acceleration tests.

Mining engineering books treat of weight *vs.* power, power of conveyors, belt efficiencies, flow of water, flow sheets of mills, efficiency of pumps, electric motors, flow of steam and air, condensers, ore dressing and strength of beams and walls.

Marine and naval engineering handbooks contain diagrams for propeller design and performance, resistance of ships, horsepower and speed, heating and ventilating, pump and condenser

efficiencies and powers, oil and coal burning, engine and boiler tests and power curves, fuel consumption, acceleration, and costs.

Estimating handbooks give diagrams of costs of all kinds of engineering and contracting work, efficiency, relative value, weight and power, mechanical resistance, wire and electricity, belts and machinery.

Natural gas, electrical railway, overhead lines, electric light and heat, waterworks, concrete and structural steel handbooks give diagrams pertaining to their special functions.

Automobile engineer's handbooks list in diagrams such things as standard chassis lengths, speed rating, steel characteristics, hardness of metals, horsepower *vs.* revolutions per minute of gasolene motors, tractive effort and horsepower, gas consumption *vs.* horsepower, cost of truck operation, engine detail charts for design, airplane propellers, fan blade calibration, efficiency of gearing, and road resistance *vs.* tractive effort.

Hydraulics handbooks treat of flow of water in open channels, streams and pipes, flow over weirs, and comparison of various formulas.

Highway inspector's handbooks give examples of diagrams such as equivalent of inches in decimal parts of a foot, volumes of earthworks, length and volume of roadway, quantities of material for various road sections, broken stone volumes, resistance of rock to abrasion, weight and volume relations for dry sand, asphalt and tar.

Fan engineering handbooks treat of heater surface and air temperature, rates of heat transmission, relation of altitude to air properties, specific weight of water vapor.

Handbook of machine shop management has organization, production records, expense analyses, and cost accounts.

Examples for Chapter I

1. Illustrate by diagrams the three classes of diagrams mentioned in this chapter.
2. Enumerate the persons or professions to whom the diagrams you use in Ex. 1 would be of interest.
3. State the kinds of diagrams which have been standardized and the advantage derived from standardization.
4. What class of diagrams would be found in most engineering handbooks and for what reason? Illustrate.
5. What diagrams would be found only in special handbooks? Illustrate.

CHAPTER II

KINDS OF GRAPHS

Before making a graph we must have the data necessary for plotting it such as given by tables of statistics, experiments or observations or indicated by a formula. With such information at hand the first step is to decide what type of diagram shall be used to best illustrate the problem and second to determine how the diagram shall be made. These two decisions depend on what class of use the diagram is to have and the size of it. The classes of use are two, *viz.*:

	Object	Size Determined
1. Personal	Reference Illustration Analysis Research Computation	By use on desk or in pocket or by commercial sizes of plotting paper
2. Public....	A. Publication (Books or Bulletins)	Reference Illustration Analysis Research Computation
	B. Use at Lectures....................	Reference Illustration Analysis
	C. Use at Exhibits....................	Reference Illustration Analysis

Reference Graphs.—A graph, like a general table, may be prepared with no other object in view than to present in graphical form a given set of facts. A curve showing the value of coal mined over a period of years or one showing the exports of automobiles is a reference graph. In general they are seldom of value unless thay carry a time series as the curves just mentioned. They must be used with care and should be simple and clear to be easily comprehended by eye-minded readers. Such curves are most effectively applied to results rather than raw materials.

Never show a graph unless it helps to bring out some significant relationships more clearly than text and tables.

Illustrative graphs differ from reference graphs in being inclusive rather than selective. A bar diagram showing the number of deaths from given causes is illustrative. It is useful in print as well as in lectures or exhibits because it helps to fix in the mind of reader some important fact that may be the keynote of a discussion. Such a graph should be very simple as it is to appeal to visual memory. An illustrative diagram may be comparatively complex and not self explanatory if used in a lecture where the speaker has the opportunity of pointing out its significance. It also gives the audience something to look at and helps hold their attention. This advantage is lost when the lecturer has too many diagrams or shows more than one at a time or spends too much time in adjusting one after the other.

Analytical graphs are seldom used except in conjunction with printed text or lecture. At an exhibit too much explanation would be required. They may be introduced into a discussion in order to show visually a relationship that the author wishes to emphasize. A graph containing two curves is analytical, as one curve of values, one of production. Such a graph is of distinct value because the correlation is made much plainer by the curves than by text and tables alone.

Research graphs are those helping to establish an unknown correlation as a result of plotting experiments or other data. Such a graph as illustrates the relation of horsepower and gasolene consumption in an internal combustion engine is an example. They are used largely in engineering.

Computation diagrams are used to lessen the tedious computing so often required in many branches of engineering and science. They are constructed for personal use, to a large scale to obtain accuracy and to a smaller scale for publication in books or bulletins. Column or gearing calculations are examples of such diagrams. Some mathematical knowledge is necessary to enable one to construct them but they can be used by the average person with grammar school education, from written or oral instructions.

HOW GRAPHS ARE MADE

Inasmuch as a diagram can be drawn on the back of a postage stamp or enlarged to cover the side of a room, its size must be

determined by the conditions governing its use. As a rule the page of a book is generally sufficient to show all the detail that needs to be shown, especially in statistical graphics.

Nearly all diagrams depend on the location of points on the plotting paper with reference to two axes at right angles which are called coordinate axes. The perpendicular distances from a point on the paper to the coordinate axes are the coordinates of the point. The distance (Y) from the point to the horizontal axis (X-axis) is the ordinate of the point and the distance (X) from the point to the vertical axis (Y-axis) is the abscissa of the point. Ordinates above the X-axis are $+$; those below $-$. Abscissas to the right of the Y-axis are $+$; those to the left $-$.

From the above statements it is evident that graph plotting can be done in the easiest way on paper which is ruled in squares. Such paper can be purchased with squares of many different sizes, besides other paper having rectangles in place of squares. As the greatest amount of graph plotting is done with both coordinates $+$ it is evident that the parts of the coordinate axes used most will be X to the right of Y and Y above X. The common point or intersection of the axes is called the origin and is usually marked zero. Two lines are selected at right angles for the axes as far to the left and as low down as possible and still leave room for the scales to be written outside of each. This brings the zero in or near the lower left-hand corner of the page or sheet.

Note the range of values to be plotted and select scales so that all the available space is utilized. The scales should be sensible ones, if possible decimal scales. In choosing scales it is permissible and usually better to have the scale of abscissas different from the scale of ordinates. However, it is better to choose scales so that the plotted line will be inclined at nearly 45° as this increases the accuracy of interpolation. In choosing scales first decide which data go with the ordinates and which with abscissas.

Write figures along the axes to indicate the scales adopted and also indicate clearly which quantity is plotted along the horizontal axis and which along the vertical axis.

The selection of plotting paper depends on the use of the diagram and the degree of accuracy desired. It is better to use one of the types of plotting paper which can be purchased than to construct the paper oneself. There is a great variety of this

paper to choose from as the increasing use of graphical methods has created a sufficient demand to enable a profit to be made in its manufacture. In addition to the paper it will be found convenient to have such tools as 60° and 45° triangles, T square or straight edge 18 to 24 in. long, triangular engineer's scale and triangular architect's scale, inking pen, 6-in. compasses with pen attachment, small inking and pencil compasses, coarse and fine writing pens and holders, black, red, blue, green, brown, yellow, orange and other colored inks, 4H drawing pencil, protractor, curved ruler, coarse pointed lettering pen, slide rule and table of logarithms.

Paper in sheets and rolls, tracing cloth, and cards are for sale in standard rulings and sizes as shown in the pages following. They are carried in stock or made by Keuffel & Esser, Eugene Dietzgen, and the Codex Book Co. of New York, the Educational Exhibition Co. of Providence, R. I., and Lefax (Inc.) of Philadelphia, Pa.

In deciding on the kind of diagram to use one should have clearly in mind the possibilities of the various kinds of paper and their applicability to the problem on hand. It often happens that log-log or semi-log paper would be preferable to rectangular ruled paper or that an alignment diagram would be more useful than an intercept diagram. Training in graphical methods will result in an increase in the number of diagrams adapted for the proper representation of the problem at hand rather than the continuation of the wrong and misleading methods so often used in graphical work.

A diagram should not be too high, neither too long, and discretion in the use of scales on both axes will produce a diagram which will give a maximum of accuracy on either axis.

Codex Papers.—Codex papers have rectilinear rulings of 4, 5, 6, 8, 10, 12, 16 and 20 per inch both ways and in millimeters. They come in thin and thick paper in sizes 4¼″ × 7¼″, 8½″ × 11″, 11″ × 17″. The ruled space is 6″ × 9″ on 8½″ × 11″ paper.

Poly-purpose papers.—6″ × 9″ plate on 8½″ × 11″ paper, ruled 20, 12 × 20 (72 div. × 180 div.), 12″ × log (72 div. × 3 cycles). Fig. 2*A&B*. Fig. 3.

Multi-purpose.—17″ × 11″ (5 log cycle long way −62 div. short way) spaced equal to typewriter spacing.

Other Papers.—1⁄12 div. long way, 1⁄20 div. short way; 1⁄20 div. long way and log short way.

Daily Record.—1⁄12 div. long way, 1⁄20 div. short way; 1⁄20 div. long way and log short way. Fig. 2B.

Weekly Records.—$\frac{1}{4} \times \frac{1}{20}$ div.

Monthly Record.—12×20 div.

Log.—Both ways $4\frac{1}{4}'' \times 7\frac{1}{4}''$ (1 cycle $\times$ 2 cycles), $8\frac{1}{2}'' \times 11''$ (2 cycles $\times$ $2\frac{3}{4}$ cycles), $17'' \times 11''$ (5 cycles $\times$ 3 cycles). Fig. 3 and 11.

Polar Chart.—$8\frac{1}{2}'' \times 11'' - 360°$. Fig. 6.

Isometric.—$8\frac{1}{2}'' \times 11''$.

Trilinear.—$8\frac{1}{2}'' \times 11''$. Fig. 3.

Monthly Records.—$8\frac{1}{2}'' \times 11''$ sheet, 2 rulings on same chart. Upper half 60 spaces vertically $\times$ 132 spaces horizontally. Lower half 60 spaces vertically $\times$ 96 spaces horizontally.

Chart Cards.—$4'' \times 6''$. charting area, $2\frac{1}{2}'' \times 4\frac{1}{3}''$ 50 spaces at 20 per inch high $\times$ 52 spaces long 12 per inch.

Computation Sheets. $8\frac{1}{2}'' \times 11''$ with spacing $\frac{3}{10}''$ approx. quadrille ruling.

Profile Paper.—$\frac{1}{4}'' \times \frac{1}{20}''$ in. sheets $15'' \times 42''$ engraving, rolls 20″ and 10″ wide in green and orange and on paper, muslin tracing cloth and tracing paper. $\frac{1}{4}'' \times \frac{1}{30}''$ in sheets $13\frac{1}{2}'' \times 42''$ engraving and in rolls with 20″ and 9″ engraving—green and orange, paper, muslin, tracing cloth and tracing paper. $\frac{1}{5}'' \times \frac{1}{25}''$ paper, engraving $15'' \times 42''$. Fig. 5 and 7 & 8.

Profile-plan Paper.—$\frac{1}{4}'' \times \frac{1}{20}''$. engraving 10″ wide which is $\frac{1}{2}$ the width of paper whose upper half is blank for notes, etc. Comes in green and orange and 50-yd. rolls. Same $\frac{1}{4}'' \times \frac{1}{30}''$, 9″ wide.

Standard Cross-section Papers.—$\frac{1}{10}'' \times \frac{1}{10}''$. sheets and rolls. Paper, muslin and tracing cloth and paper. Green, blue and orange engraving $16'' \times 20''$ for sheets, 20″ wide for rolls. $\frac{1}{16}'' \times \frac{1}{16}''$, $17'' \times 22''$ sheets and 20″ rolls. Same as above. $\frac{1}{8}'' \times \frac{1}{8}''$, $16\frac{1}{4}'' \times 21\frac{7}{8}''$ sheets, green, orange or blue. $\frac{1}{5}'' \times \frac{1}{5}''$, $16'' \times 20''$ sheets, green, orange or blue. $\frac{1}{12}'' \times \frac{1}{12}''$, $16'' \times 20''$ sheets, green. Fig. 6 and 9.

Millimeters, 40×50 cm. sheets drawing paper or tracing paper, green blue or orange. In rolls 50 and 75 cm. wide, green and orange. Fig. 10.

Simplex Cross-section Paper.—$\frac{1}{8}'' \times \frac{1}{8}''$ in orange, rolls 30″ engraving width, paper only.

Ruled Cross-section Paper.—$\frac{1}{5}'' \times \frac{1}{5}''$ sheets $16'' \times 21''$ blue. $\frac{1}{10}'' \times \frac{1}{10}''$ sheets $16'' \times 21''$ blue. $\frac{1}{8}'' \times \frac{1}{8}''$ sheets $16'' \times 21''$ blue. Fig. 4.

Topog. Paper.—Sheets $16'' \times 21''$ 400 ft. to the inch ruled red and blue. Fig. 4.

Constructor's Sketch Paper.—$\frac{1}{20} \times \frac{1}{10}$ 5th lines heavy printed neutral tint. Engraving $5'' \times 7\frac{1}{2}''$ tracing paper or drawing paper. $7\frac{1}{2}'' \times 10''$ tracing paper or drawing paper. $10'' \times 15''$ tracing paper or drawing paper.

Log Paper.—$10'' \times 10''$ neutral tint, sheets. Fig. 11.

Webbs' Coordinate Paper.—Engraving $8\frac{3}{4} \times 11\frac{3}{8}$, $11\frac{3}{8} \times 17\frac{3}{4}$ ruling approx. $\frac{1}{2}''$ subdivided 10×10. Squares 180×220, 240×350. $8'' \times 10\frac{1}{2}''$. 160×220 sqs. $10\frac{1}{2}'' \times 16''$. 220×330 sqs. Fig. 10.

Isometric Cross-section Paper.—$6'' \times 9''$, $9'' \times 12''$, $12'' \times 18''$ neutral tint drawing paper.

Polar Coordinate Paper.—$7'' \times 10''$ drawing and tracing paper. Fig. 6.

Engraved paper, rectangular spaces, printed in green ink on paper of good quality thin enough to blue print. Paper of letter size $8\frac{1}{2}'' \times 11''$ in scales of $\frac{1}{6}''$, $\frac{1}{20}''$, millimeter, *year by day*, *baragraph*, 5 bars per page, Fig. 15, $\frac{1}{6}$ scale in black ink, $30'' \times 38''$, white paper. *Arith.-log* 6×9 engraving on $8\frac{1}{2}'' \times 11''$, 60 $\frac{1}{10}''$ spaces on short edge and 3 log scales of $3''$ base on long edge.

Same with 5 log scales instead of 3.

Same with 4 log scales instead of 3.

Same as first with $\frac{1}{2}$ the no. of $\frac{1}{10}''$ lines.

Same as first with 2 log scales instead of 3.

Same as first with 1 log scale instead of 3.

Same as first with 90 $\frac{1}{10}''$ spa. on long edge and 2 log scales on short side.

Arith.-log paper in *blue* ink, $12''$ sq. engraving, paper $16''$ sq., 2 log scales on vertical and 60 divisions on horizontal.

Same $18''$ sq. engraving with $20'' \times 21''$ paper. One log scale in vertical and 360 divisions on horizontal side.

(*A*) Large size *coordinate paper*, green on white, tenths of inch. $16'' \times 20''$ engraving, $18'' \times 23''$ paper.

(*B*) Same in orange on thin tracing paper.

(*C*) Similar to (*A*) $\frac{1}{10}''$ sq. engraving $20''$ wide in rolls 22 in. wide 50 yds. long.

Like (*C*) but on tracing paper with orange ink.

(*D*) Twelfths of an inch green ink, engraving $16'' \times 20''$ on heavy drawing paper $18'' \times 23''$.

(*E*) 4×20 to an inch, engraving $15'' \times 42''$, green on 17×44 paper, every 10th line horizontally and every 100th line vertically is heavy.

(*F*) Like (*E*) but engraving $20''$ wide on $22''$ wide drawing paper in 50-yd. rolls.

(*G*) *Millimeter* paper engraving 40×50 cm., green ink on paper $18'' \times 23''$.

(*H*) Like (*G*) on thin tracing paper in orange ink.

(*I*) *Millimeter* engraving 50 cm. wide, green, on paper $22''$ wide in 50-yd. rolls.

(*J*) Same as (*I*) on tracing paper in orange.

(*K*) *Log* paper engraving $10'' \times 10''$, 1 log scale each way on $11\frac{1}{4} \times 11\frac{1}{2}''$ paper. Neutral tint ink. Fig. 11.

(*L*) Same with 2 log scales in each direction in orange on thin bond paper.

(*M*) *Isometric* paper 12″ × 18″ engraving in neutral tint on thin drawing paper 13″ × 19″.

(*N*) *Days in year* paper engraving 7″ × 12″ green ink on 8″ × 14″ paper.

Curve Cards:

4″ × 6″— 7 spaces high—12 spaces long, engraving in lower left corner.
4″ × 6″—10 spaces high—12 spaces long, engraving in lower left corner. Fig. 12.
4″ × 6″— 7 spaces high—31 horizontal spaces.
4″ × 6″—10 spaces high—31 horizontal spaces.
4″ × 6″— 7 spaces high—10 horizontal spaces.
4″ × 6″—10 spaces high—10 horizontal spaces.
4″ × 12″— 7 spaces high—52 horizontal spaces. Fig. 12.
4″ × 12″—10 spaces high—52 horizontal spaces.
4″ × 12″— 7 spaces high—60 horizontal spaces.
4″ × 12″—10 spaces high—60 horizontal spaces. Fig. 12.

In Figs. 2 to 15 following are shown the principal types of plotting and cross section paper used for charting.

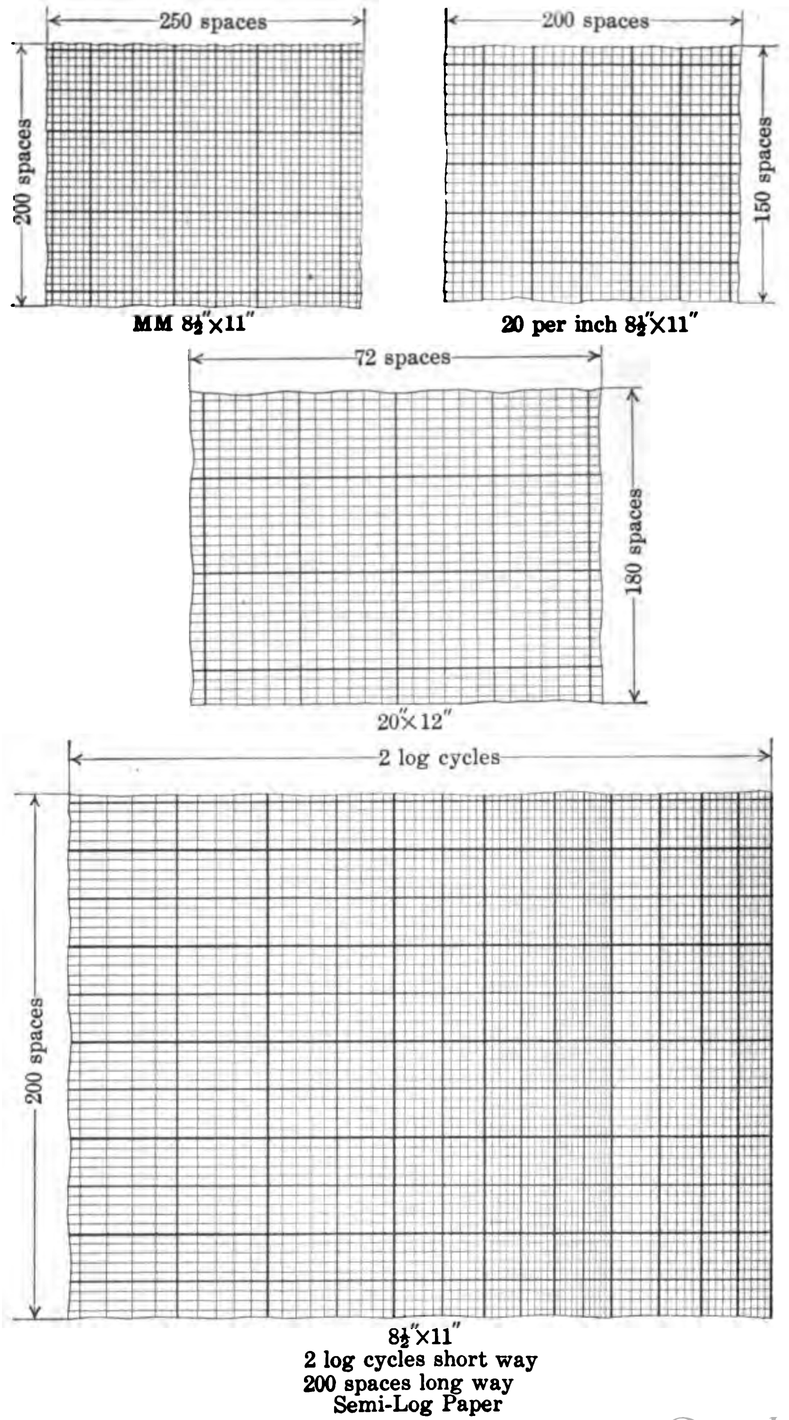
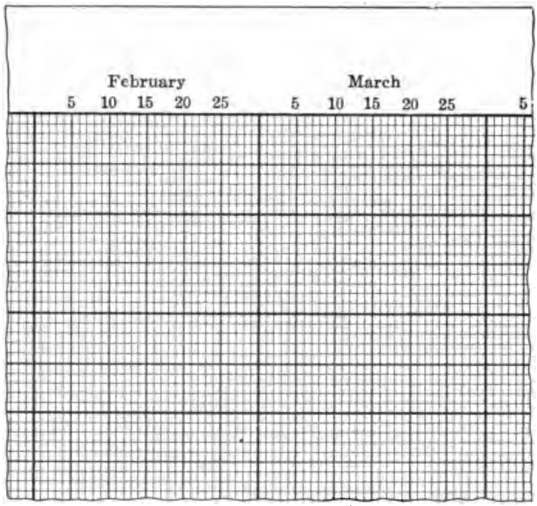
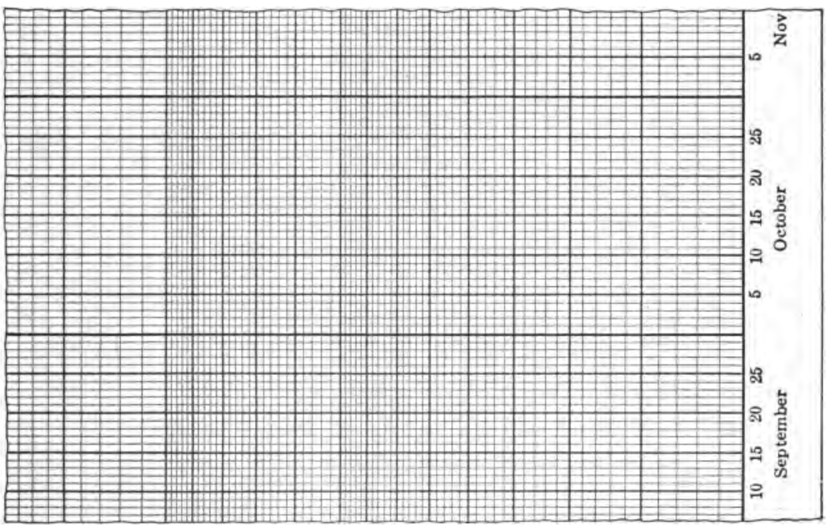


Fig. 2A.—Plotting papers.

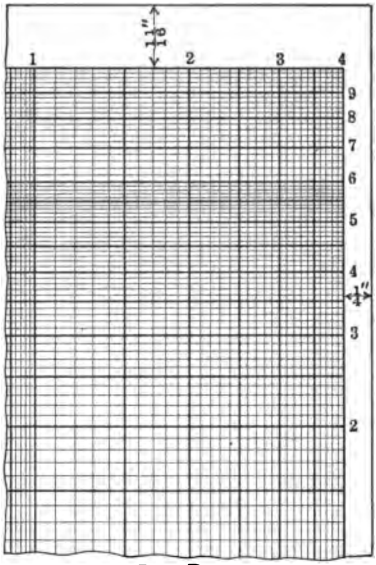


Daily Record 17″×11″

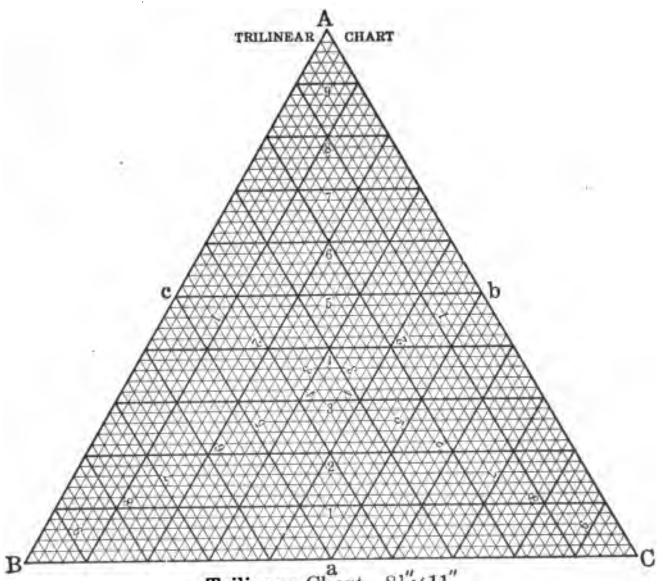


Semi-Log and Daily Record
Arith. ″

FIG. 2B.—Plotting papers.

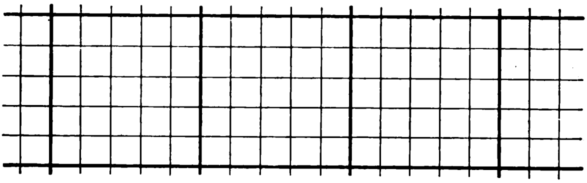


Log Paper
$4\frac{1}{4}'' \times 7\frac{1}{4}''$ 1 cycle & 2 cycles
$8\frac{1}{2}'' \times 11''$ 2 " & $2\frac{3}{4}$ "
$17'' \times 11''$ 3 " & 5 "

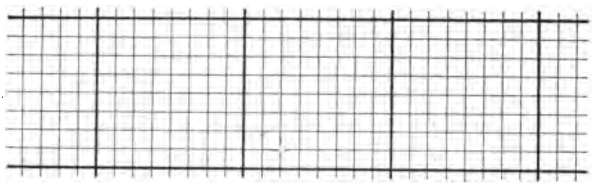


Trilinear Chart $8\frac{1}{2}'' \times 11''$

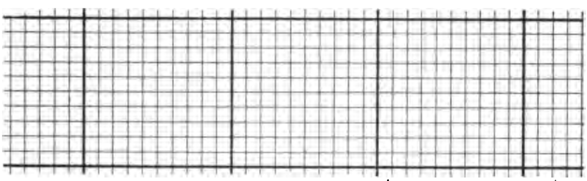
FIG. 3.—Plotting papers.



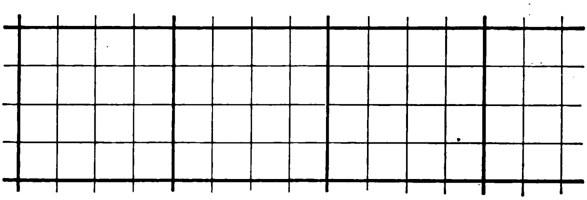
Sheets, 16 × 21 in., 5 × 5 to the inch, ruled blue.



Sheets, 16 × 21 in., 8 × 8 to the inch, ruled blue.



Sheets, 16 × 21 in. 10 × 10 to the inch, ruled blue.

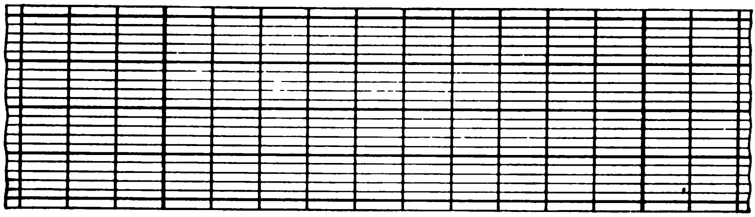


Topographical paper, sheets, 16 × 21 in., 400 feet to the inch, ruled red and blue.

FIG. 4.—Ruled cross section papers.

PROFILE PAPERS AND CLOTHS

In sheets and in continuous rolls



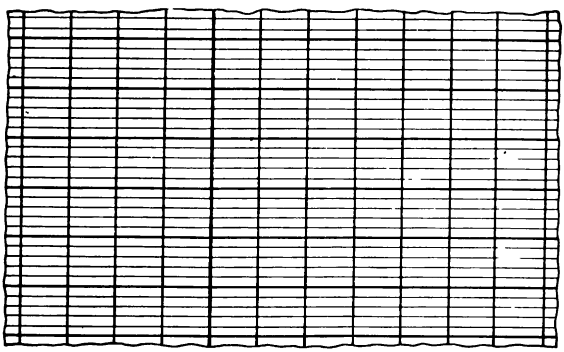
4 × 20 to the inch.

SHEETS

Green, engraving 15 × 42 in., drawing paper.
Orange, engraving 15 × 42 in., drawing paper.

CONTINUOUS

Green, engraving 20 in. wide, drawing paper.
Orange, engraving 20 in. wide, drawing paper.
Green, engraving 10 in. wide, drawing paper.
Orange, engraving 10 in. wide, drawing paper.
Green, engraving 20 in. wide, mounted on muslin.
Orange, engraving 20 in. wide, mounted on muslin.
Green, engraving 10 in. wide, mounted on muslin.
Orange, engraving 10 in. wide, mounted on muslin.
Orange, engraving 20 in. wide, tracing paper.
Orange, engraving 10 in. wide, tracing paper.
Orange, engraving 20 in. wide, tracing cloth.
Green, engraving 20 in. wide, Columbia cloth.
Orange, engraving 20 in. wide, Columbia cloth.



Profile Paper 4 × 20 to the inch.

In sheets, engraving 13½″ × 42″ printed in green or orange.
In rolls, engraving 20 in. wide printed in green or orange.
In rolls, engraving 9 in. wide, printed in green or orange

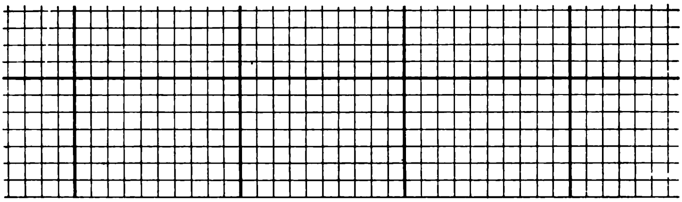
Tracing Paper and Cloth

In rolls, tracing paper 20 in. wide, printed in orange only.
In rolls, tracing paper 9 in. wide, printed in orange only.
In rolls, tracing cloth 9″ × 20″ printed in green or orange.

FIG. 5.—Profile papers and cloths.

CROSS SECTION PAPERS AND CLOTHS

In sheets and in rolls (continuous)



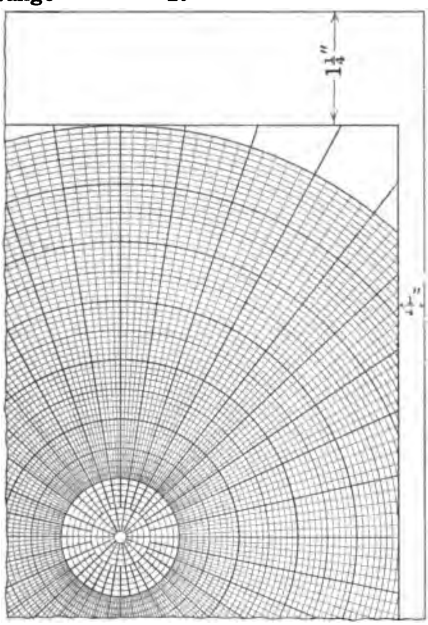
10×10 to the inch

SHEETS

Green, engraving	16×20 in.,	Drawing	Paper
Orange “	16×20 “	do.	do.
Blue “	16×20 “	do.	do.
Orange “	16×20 “	Tracing	Paper

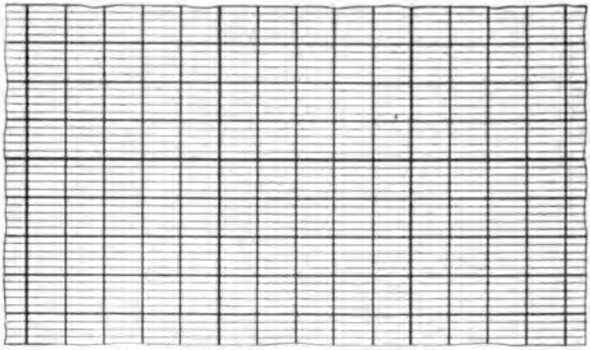
CONTINUOUS

Green, engraving	20 in. wide,	Drawing	Paper
Orange “	20 “ “	do.	do.
Green “	20 “ “	mounted on	muslin
Orange “	20 “ “	do.	do.
Orange “	20 “ “	Tracing	Paper
Orange “	20 “ “	Tracing	Cloth
Green “	20 “ “	Columbia	Cloth
Orange “	20 “ “	“	“

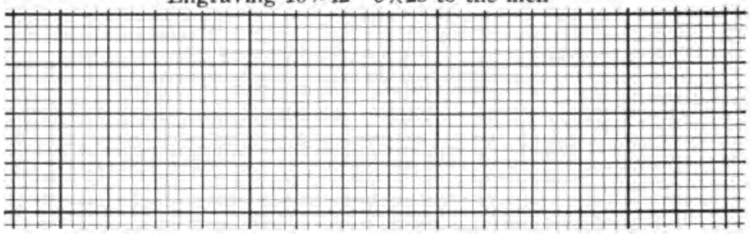


Polar Co-ordinate Paper $6\frac{3}{4}'' \times 10\frac{1}{2}''$

FIG. 6.—Polar plotting paper and cross section papers.



Profile Paper–Green or orange
Engraving 15″×42″–5×25 to the inch



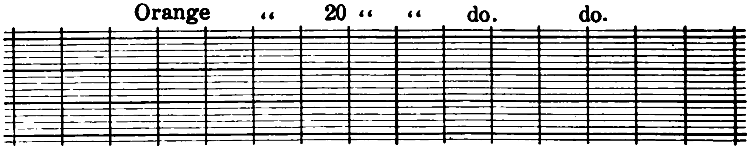
16×16 to the inch

SHEETS

Green,	engraving	17×22	in.,	Drawing Paper
Orange	"	17×22	"	do. do.
Blue	"	17×22	"	do. do.
Orange	"	17×22	"	Tracing Paper

CONTINUOUS

Green,	engraving	20	in.	wide,	Drawing Paper
Orange	"	20	"	"	do. do.
Green	"	20	"	"	mounted on muslin
Orange	"	20	"	"	do. do.



4×30 to the inch

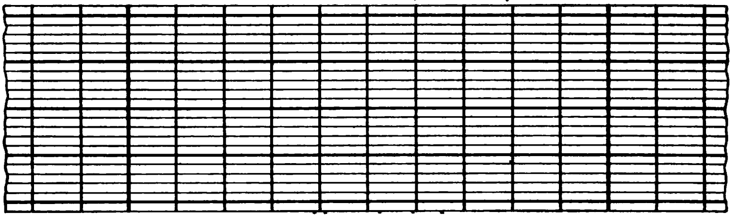
Profile-Plan Papers and Cloths

Green,	engraving	9	in.	wide,	Drawing Paper
Orange,	"	9	"	"	do. do.
Orange,	"	9	"	"	Tracing Paper
Orange,	"	9	"	"	Tracing Cloth

FIG. 7.—Profile plotting papers.

PROFILE PAPERS AND CLOTHS

In sheets and in rolls (continuous)



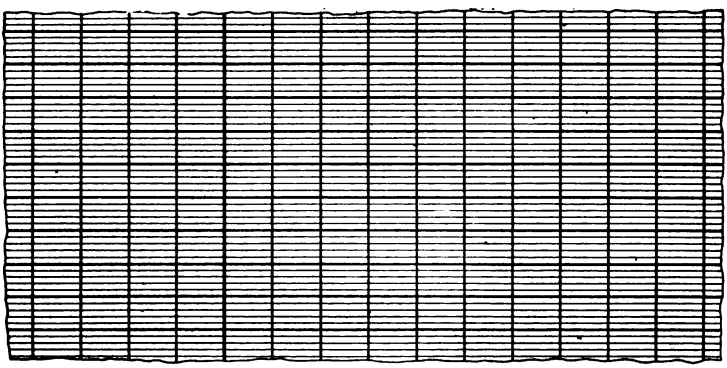
4 × 30 to the inch.

SHEETS

Green, engraving 13½ × 42 in., drawing paper.
Orange, engraving 13¾ × 42 in., drawing paper.

CONTINUOUS

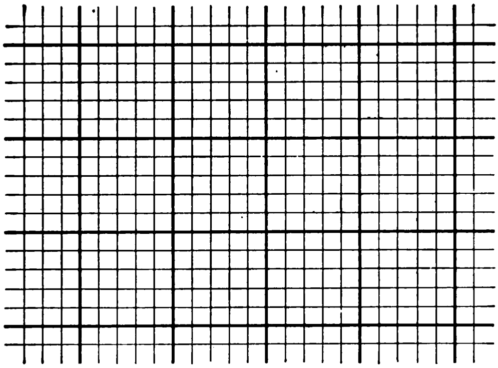
Green, engraving 20 in. wide, drawing paper.
Orange, engraving 20 in. wide, drawing paper.
Green, engraving 9 in. wide, drawing paper.
Orange, engraving 9 in. wide, drawing paper.
Green, engraving 20 in. wide, mounted on muslin.
Orange, engraving 20 in. wide, mounted on muslin.
Green, engraving 9 in. wide, mounted on muslin.
Orange, engraving 9 in. wide, mounted on muslin.
Orange, engraving 20 in. wide, tracing paper.
Orange, engraving 9 in. wide, tracing paper.
Orange, engraving 20 in. wide, tracing cloth.
Green, engraving 20 in. wide, Columbia cloth.
Orange, engraving 20 in. wide, Columbia cloth.



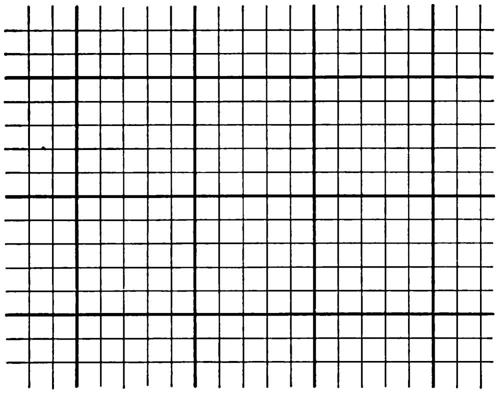
Profile paper 4 × 20 to the inch.

Rolls 20″ × 10″ wide printed in green, or orange.
Tracing cloth in orange only.
Tracing paper in orange only.
Paper in sheets engraving 15″ × 42″ printed in green or orange.

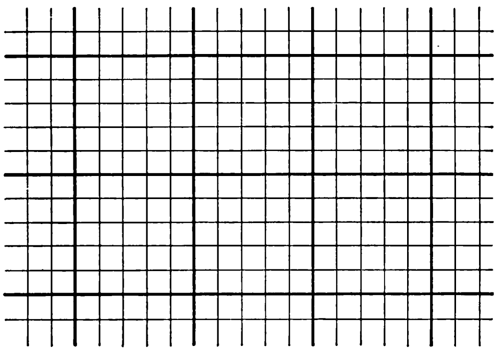
FIG. 8.—Profile papers and cloths.



CROSS SECTION PAPER.
5 × 5 to the half inch.
Printed in green, orange or blue.
In sheets engraving 16″ × 20″.
Also tracing paper in orange only.



CROSS SECTION PAPER.
8 × 8 to the inch, fifth lines heavy. In sheets engraving 16¼″ × 21¼″.
Printed in green, orange or blue.
Tracing paper orange only.

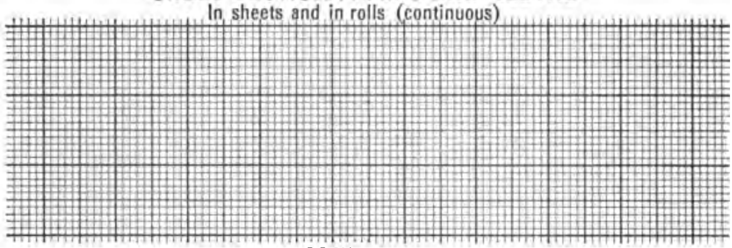


CROSS SECTION PAPER.
8 × 8 to the inch, orange, continuous, engraving 30 in. wide.

FIG. 9.—Cross section papers.

CROSS SECTION PAPERS AND CLOTHS

In sheets and in rolls (continuous)



Millimeters

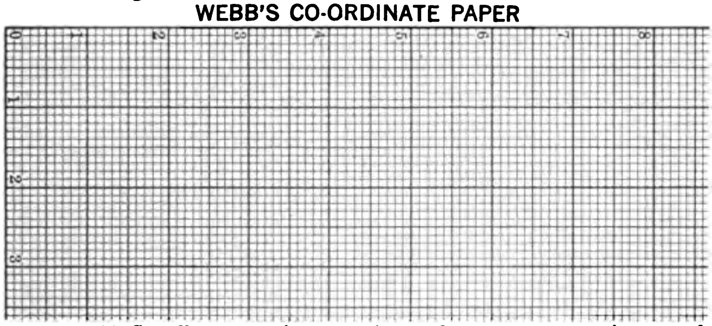
SHEETS

Green, engraving	40×50	cm. wide,	Drawing Paper	
Orange "	40×50	" "	do.	do.
Blue "	40×50	" "	do.	do.
Orange "	40×50	" "	Tracing Paper	

CONTINUOUS

Green, engraving	50	cm. wide,	Drawing Paper	
Orange "	50	" "	do.	do.
Green "	50	" "	mounted on muslin	
Orange "	50	" "	do.	do.
Green "	75	" "	Drawing Paper	
Orange "	75	" "	do.	do.
Green "	75	" "	mounted on muslin	
Orange "	75	" "	do.	do.
Orange "	50	" "	Tracing Paper	
Orange "	75	" "	do.	do.
Orange "	50	" "	Tracing Cloth	

WEBB'S CO-ORDINATE PAPER

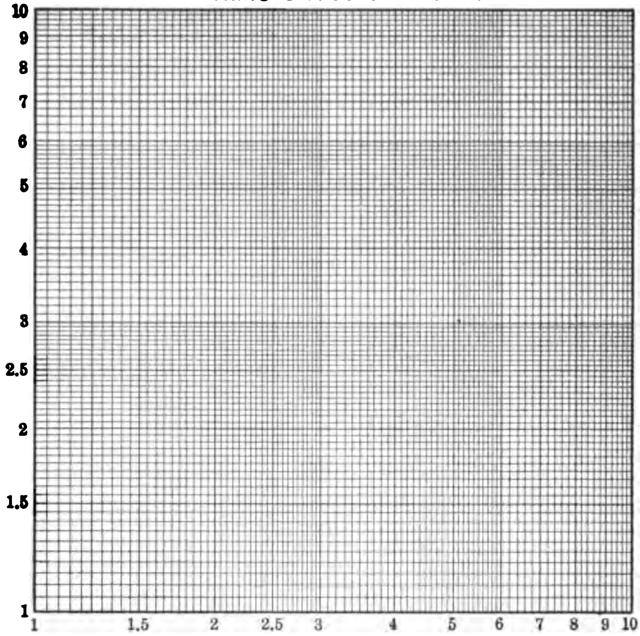


Webb's Co-ordinate paper is a convenient and accurate cross-section paper for drafting rooms, technical schools, laboratories, etc. It is printed from accurate engravings in a neutral olive tint which can be photographed or photo-printed. The scale of the rulings is between the English and French (½ inches and centimeters) subdivided 10×10. The lines are numbered in two directions for ready reference to any point on the paper and the sheets are punched for portfolio binding. A table of natural tangents is printed on the margin of some of the larger size sheets, for laying off angles.

Best Linen Record Paper,	$8\frac{3}{4}\times11\frac{3}{8}$	in.,	180×220	squares
" " " "	$11\frac{3}{8}\times17\frac{3}{4}$	"	240×350	"
Best thin Bond Paper,	$8\frac{3}{4}\times11\frac{3}{8}$	"	180×220	"
" " " "	$11\frac{3}{8}\times17\frac{3}{4}$	"	240×350	"
" " " "	$8\times10\frac{1}{2}$	"	160×220	"
" " " "	$10\frac{1}{2}\times16$	"	220×330	"
Smooth Drawing Paper,	$8\times10\frac{1}{2}$	"	160×220	"

Fig. 10.—Cross section papers.

LOGARITHMIC CROSS SECTION PAPER



Sheets, engraving, 10×10 in., neutral tint

On this paper the scales on each side are logarithmic instead of uniform as in other cross section papers. The numbers and divisions marked are placed at such points that their distances from the origin are proportional to the logarithm of such numbers instead of to the numbers themselves.

Fig. 11.—Logarithmic paper.

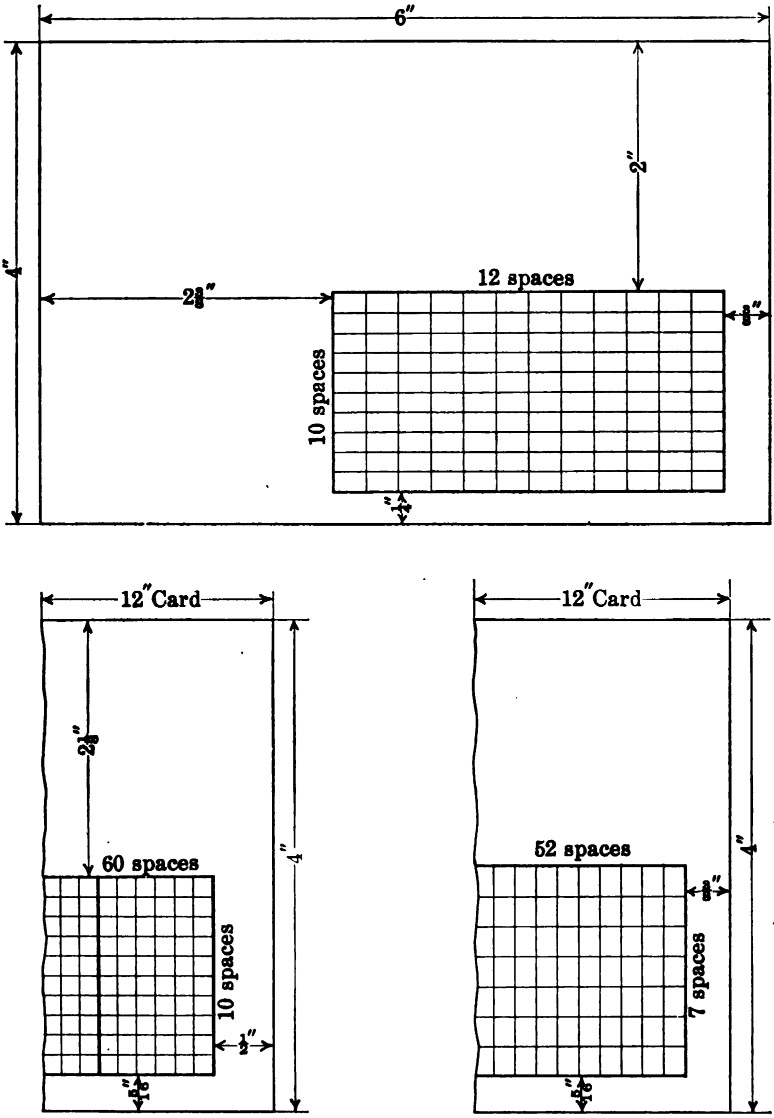


FIG. 12.—Filing cards for records 4 by 6 and 4 by 12.

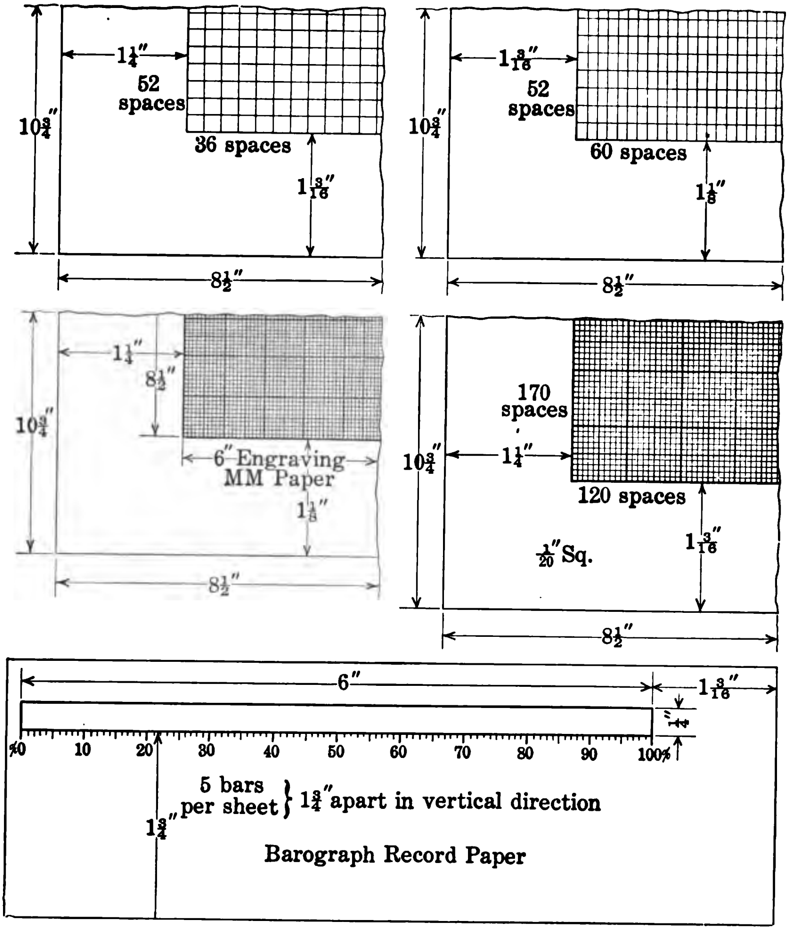


FIG. 13.—Special record papers.

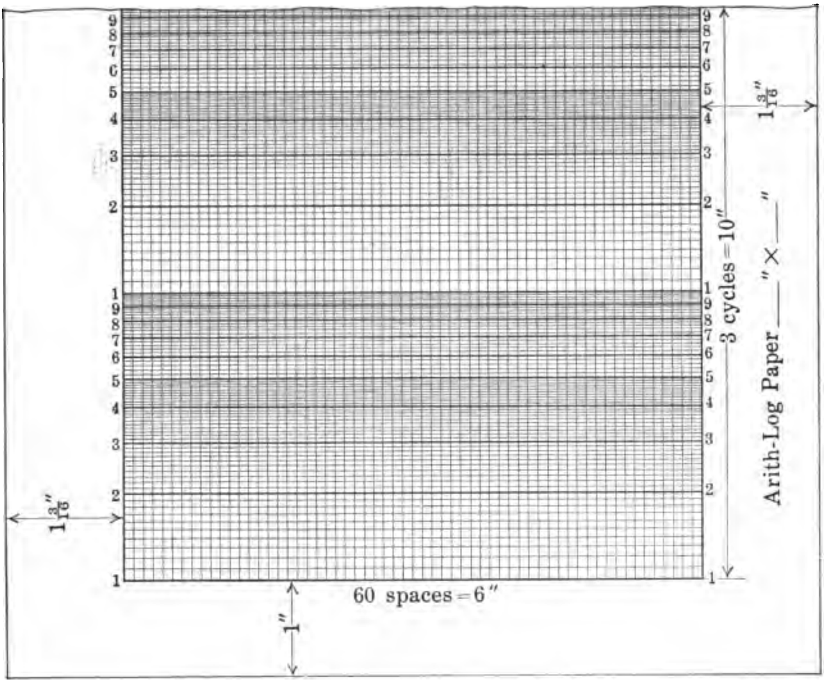
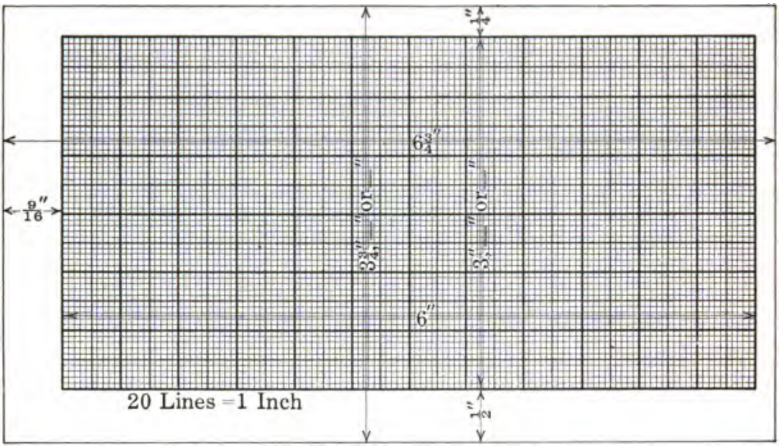


Fig. 14.—Arith-Log paper.



Widths are 3¾″, 6¾″ or 9¾″. Engraving is 3″, 6″ or 9″.

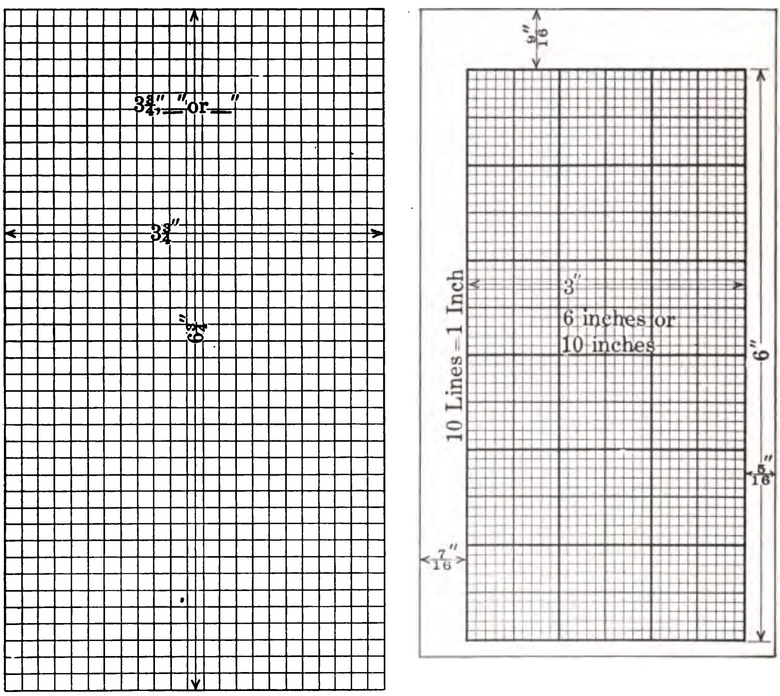


Fig. 15.—Plotting paper in sheets punched for holders.

CHAPTER III

MAKING OF DIAGRAMS

For the guidance of those about to take up graphical methods it may be well to give a few universally recognized rules to govern the making of diagrams. There has been no definite set of standards adopted by engineers or statisticians to govern this work, although a joint committee from the leading engineering societies and other organizations made a preliminary recommendation in 1915. This has not yet been followed by a final report nor has the first one been adopted.

Messrs. Day, Reed and Seecrist are the authors of a set of rules which was published in the *Weekly Statistical News* at Washington, D. C., Oct. 10, 1918. This contains much good advice and will be quoted freely in the pages immediately following.

Standardization gives the maker and reader of diagrams complete familiarity with the various graphic forms used. It also facilitates the comparison of data displayed in different diagrams and simplifies the transfer of plots from one sheet to another. It also aids in developing simplicity of form which is a primary requisite of the graphical method.

Readers of statistical diagrams should not be required to compare magnitudes in more than one dimension. Visual comparisons of areas are particularly inaccurate and should not be necessary in reading any statistical graphical diagram.

Suggestions for diagrams are as follows (abstract from Day, Reed and Seecrist and committee report):

1. General arrangement of a diagram should proceed from left to right and from bottom to top.
2. Numerals for the scales of a diagram should be placed at the left and at the bottom, *viz.*, along the respective axes.
3. All numerals and lettering on a diagram should be placed so as to be easily read from the bottom or right-hand edge of the diagram as the bottom.
4. Use linear magnitude for quantities rather than areas or volumes.
5. The vertical scale should be selected to bring the zero line on the

diagram but if it will not appear normally make a horizontal break in order to show it.

6. The base or zero lines of the scales, or lines which represent standards of attainment should be sharply distinguished from the other coordinate lines.

7. When curves are drawn on log coordinates the limiting lines of the diagram should each be at some power of 10 on the log scales.

8. The curve lines of a diagram should be sharply distinguished from the ruled lines.

9. Do not show more coordinate lines than are necessary to guide the eye in reading the diagram.

10. When curves are obtained from a series of observations, it is advisable to indicate clearly on the diagram all the points representing the separate observations.

11. The scale intervals on any single diagram should be exactly proportional to the gradations of number, size or time represented. (The log scale is an exception to this rule.)

12. Items should be grouped so as to facilitate the comparison of items most significantly related. Within groups some systematic order should be adopted. The most serviceable arrangements are according to (*a*) **sequence** of the items in time with the *earliest* at the left, or (*b*) the **size** of the items with the *largest* at the *top* or at the *left*, or (*c*) the **favorableness** of the items, the *most favorable* at the top or at the left.

13. Data shown graphically in a diagram should be given in tabular form beside or within the diagram or close by in the text. Do not, however, place figures so as to disturb or distort the visual impressions conveyed by the chart.

14. The title of a diagram should be made as clear and complete as possible. Sub-titles or descriptions should be added if necessary to insure clearness.

In choosing forms for graphical presentation the following suggestions from Day, Reed and Secrist are reccommended.

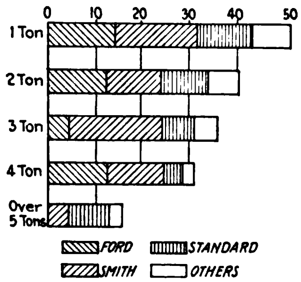
1. **For Simple Comparisons of Size.**

(*a*) *Bars* are the most satisfactory. In general all the bars used in the diagrams of a simple study should be of a uniform width (see Fig. 16).

(*b*) When a large number of separate items have to be shown in a single diagram *lines* may be employed in place of bars (Fig. 17).

(*c*) Bars or lines are best placed horizontally (Figs. 16 and 17).

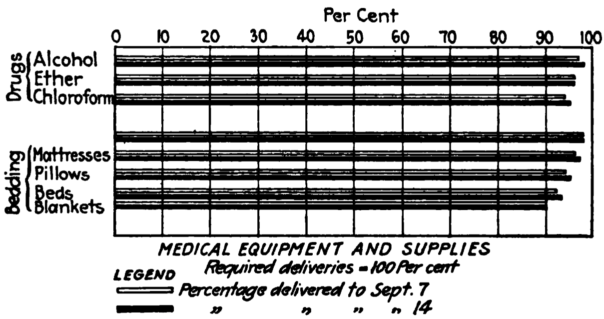
MOTOR TRUCK PRODUCTION, 1919



Firm	Size of Truck: 1-ton	2-ton	3-ton	5-ton	over 5-ton
Ford.......	15	14	4	12	
Smith......	16	10	19	10	4
Standard...	11	8	6	5	7
Others.....	8	8	6	3	3
All.........	50	40	35	30	15

FIG. 16.

PROGRESS CHARTS



Per cent delivered to Sept. 14	Sept. 7
98	97
96	96
95	94
98	98
97	96
95	94
93	92
90	90

FIG. 17.

2. For Comparison of Component Parts.

(*a*) *Subdivided bars* are most satisfactory form (Fig. 16).

(*b*) *Cross-hatching* is the best way in which to distinguish the component parts (Fig. 16).

(*c*) *Position.*—Horizontal bars are to be preferred to vertical except when the items are separated by intervals of time in which case vertical bars should be used (Fig. 18*b*).

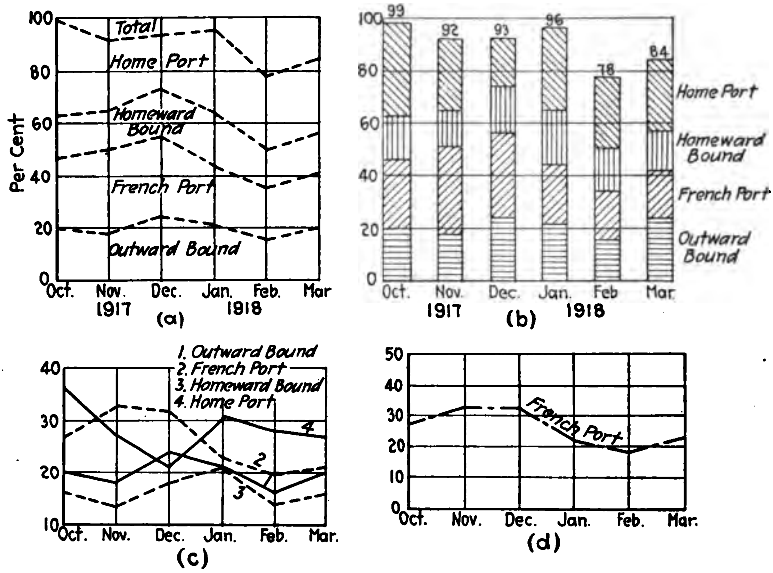
3. For Displaying Frequency Distribution.

(*a*) *Vertical columns* (histogram an alternative). In general the vertical bar or column form is to be used. The straight line histogram, however, is a satisfactory alternative.

(*b*) *Position of Scales.*—The scale for the variable is to be placed along the horizontal axis, the scale for the frequencies along the vertical axis.

4. For Showing Time Variations.

(*a*) *Straight Line Graph.*—In general the use of the straight line graph between plotted points is to be recommended (see Fig. 18*a*, *c*, *d*).



Month	Total	Outward Bound	French Port	Homeward Bound	Home Port
Oct.	99	20	27	16	36
Nov.	92	18	33	14	27
Dec.	93	24	32	18	21
Jan.	96	21	23	21	31
Feb.	78	16	20	14	28
Mar.	84	20	21	16	27

(e)

TIME VARIATIONS

TIME CONSUMED IN A TURNAROUND

FIG. 18.

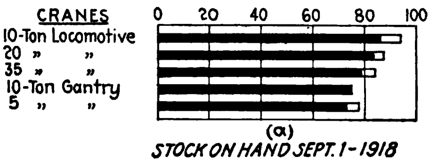
(*b*) *Positions of Scales.*—Intervals of time should be scaled invariably along the horizontal axis (Figs. 18*a*, *b*, *c*).

(*c*) *Log Scale.*—The log scale vertically is to be used when rates of change or proportionate increases or decreases are to be

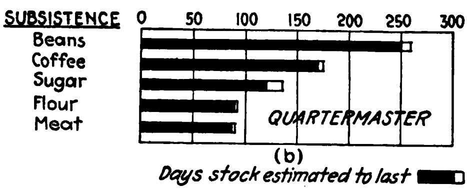
emphasized. When the log scale is employed, the limits of the scale should be some power of 10.

5. **For Showing Progress.**—The most effective graphic devices for showing progress are horizontal bars and simple and cumulative time curves (Fig. 17 and Fig. 19).

PERCENTAGE FLOATED OF TONNAGE ALLOTTED
ENGINEER EQUIPMENT
TONNAGE ALLOTTED 100 PER CENT
FLOATED TO SEPT. 14, AT PORT SEPT. 14,



Floated to Sept. 14	At port Sept. 14
85	10
83	4
78	6
75	0
73	5



Sept. 1, 1918 lbs. in thousands	Days	Aug. 1 Days
250,000	260	250
25,000	175	170
150,000	135	120
275,000	92	90
15,000	88	90

FIG. 19.

There should never be too many lines on one diagram unless they can be kept apart from one another. Lines should be distinguished by different kinds of lines as solid, broken, dash and dot, etc., or by different colors, although the latter is not recommended especially if the diagram is to be blue-printed or reproduced by photography. The meaning of the line should be printed close to it (Fig. 25).

Avoid cross references and separate the data, if there is much detail, into two or more diagrams. An overloaded diagram defeats the only purpose for which it is intended.

The ratio of vertical and horizontal scales must be chosen to bring out the fluctuations or movements which are the subject of study but not to exaggerate or render them inconspicuous. An exaggerated vertical scale has the effect of making too conspicuous a single year in which the rise was greatest, when with monthly figures the high values would be seen spread over both the adjacent years.

In making graphs for comparison the scales chosen must give a similar range of variation, otherwise the correspondence may not be evident. For example, the scales adopted to show the average consumption of tea and sugar must be ounces for the former and pounds for the latter.

There are various types of curves or diagrams used to represent happenings or phenomena. They may have mathematical or non-mathematical bases.

If they belong to the latter class, they are usually expressed either by data which at a single instant of time tends to be distributed around a central tendency and express the characteristics of a variable fact, or they express the occurrence of a homogeneous fact or condition over a period of time.

In the first case the picture of a fact is viewed in cross section, in the second it is viewed longitudinally. Time is important in the second, degree of change being expressed in relation to time, while time is of no consequence in the first. A table containing variable facts and their frequency of occurrence is called a *frequency* table and the curve illustrating the table, a *frequency graph.*

A table describing the occurrence of a fact over a period of time is a historical table and the corresponding curve a *historical graph* or "*histogram.*"

The distribution of measurements is of two types: (1) Those which form continuous series; and (2) those which form discrete series.

In the first type are those measurements which are only approximate within limits set up and which differ among themselves by infinitesimally small graduations. The measurements of natural objects fall in this class since neither size nor weight are susceptible to accurate statement.

Frequencies in discrete series are determined by the character of units in which the measurements are made. The nature of the unit determines the points at which frequencies occur,

such as wages in multiples of 25 cts. or express rates at 5 cts. per pound. In economic fields the latter series predominates.

To present a statistical fact two dimensions are needed. On the horizontal scale are plotted the individual measurements or groups and on the vertical or ordinate scale the frequency with which each measurement or group occurs. Divisions are equal on both axes. Equal distances on either scale should represent equal facts. The ratios between the two scales is most important to consider, for if the vertical scale is too large the diagram will appear high and narrow, whereas the opposite ratio will produce a long, low diagram.

The scales should be divided into units which are multiples of the rulings of the paper used.

In plotting frequency curves the measurements are grouped into classes. The smoothness of the curve depends on the class divisions. In the matter of grouping there are two opposing tendencies, *viz.*, grouping into too few classes to show variability and grouping into too many classes to give a smooth distribution.

A general rule can be laid down that the classes should be only just broad enough to make the distribution fairly smooth, that is, there should be no vacant classes except near the extremes of the range.

When successive frequencies are added together we have *cumulative frequency* series. Cumulative frequencies are helpful in furnishing continuous summaries of distributions which, reduced to a percentage basis, make it easy to determine currently, by inspection, how one-fourth, one-half, three-fourths of the frequencies are effected.

When a cumulative frequency series is plotted, the curve may extend from the lower left-hand corner to the upper right hand or from upper left to lower right, depending on the way the cumulating is done. If it is a "less than" form it follows the first, if a "more than" it follows the second.

In plotting cumulative curves, the abscissa units if they represent groups are indicated as spaces but if they represent single measurements they are denoted by points. Cumulative curves are much employed to furnish continuous pictures of what has been accomplished in the past and an indication of future trend. In order to make comparisons between different series it is best to reduce frequencies to a percentage basis which permits

of a ready means of visual judgment of the regularity of distribution through the range of measures.

Elements of annual time series of economic data may be conceived to be constituted of the following elements or component parts:

1. Secular trend or growth elements due to increase of population or development of an industry.

2. Cyclical fluctuations extending over a number of years and having more or less periodicity due to alternating periods of business prosperity and depression.

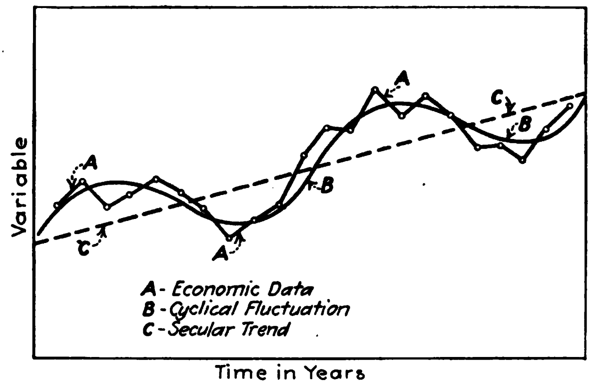


FIG. 20.—Historical curves.

3. Irregular fluctuations from year to year due to the influence of unpredictable events such as changes in fashion, war, inventions. Curves of this type are illustrated in Fig. 20. An historical curve is used to record the changes from time to time. Periods with nothing in common and units of measurement which have changed during the period cannot be compared.

Great use is made of arranging on the same sheet of paper a group of curves each one telling some phase of history but having the same measurement of time. Such a system supplies in the most convenient form one set of the factors used in every explanation of the past and forecast of the future in so far as it is based on an estimate of quantity.

They supply the rates of growth of the possible causes while reason aided by theory supplies the other set of factors, *viz.*, the nature of the dependence of the result observed in the several causes. The suggestion which an historical curve gives depends

on the scales by which it is drawn, the evil being greatest in the case of things which increase very rapidly.

In Fig. 21 at every point on curve P_2 there is the same proportional rate of increase which is also true for curves P_1 and P_3 which are identical with P_2. Each curve represents the growth in the population of London on the supposition that starting at one million it had increased for a century uniformly at about its actual mean growth for 30 years. The only difference between the curves is that the horizontal scale for P_2 is five times that for P_1 and half that for P_3.

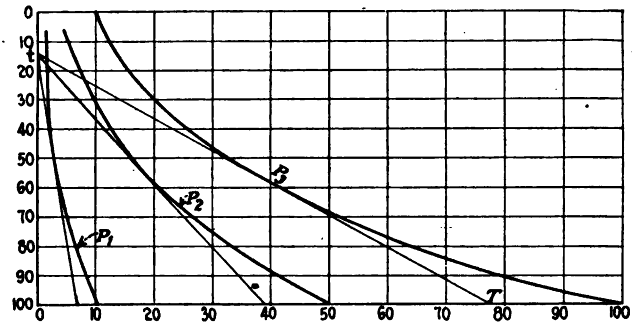


FIG. 21.—Growth of population of London based on uniformity at its actual mean growth for 30 years.

In Fig. 22 if the same scale was used for I and II it would appear as if there was a much more rapid growth in sugar consumption than tea, but if we compare pounds of sugar with ounces of tea we find there is very little difference.

The plotting of historical curves is sometimes misleading as to comparative rates of growth of different things. If we were concerned with absolute amounts it would not be so bad but we want the percentage of increase or proportional rates of increase, that is, the ratio in which the increase during say a year bears to the amount at the beginning of the year. It is also difficult for the eye to judge without artificial aid the ratio of increase at different parts of the same or different curves. One method is to make the horizontal distance in Fig. 21 represent the logarithm of the amounts instead of the true amounts. By this method lines of equal slope denote equal rates of change and the three curves of this diagram (Fig. 21) would become parallel straight lines. The diagrams heretofore described have been

constructed on an arithmetic basis treating of absolute values only and giving differences. Very often the difference method is misleading in giving absolute values based on a zero not visible on the diagram and showing an increase or decrease which is not in any constant ratio to the preceding quantity.

The ratio method of plotting has been described in detail by Prof. Irving Fisher in a paper published by the American Statistical Association in the June, 1917, publication.

The growth and use of this method has not been as large as its value warrants, but as soon as its simplicity is realized there will be no doubt of its displacing the difference method for statistical plotting.

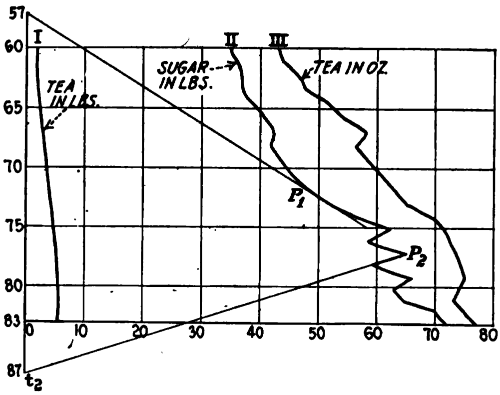


FIG. 22.—Comparative historical curves of tea and sugar consumption.

The ratio diagram has several advantages over the difference diagram. A straight-line graph in a ratio plot means uniformity in percentage growth, while the same uniformity in a difference plot will be represented by an exponential curve. The ends of such a curve are almost useless but a ratio line is of the same value at all points. Another advantage is its use in forecasting. In business a forecast is made by assuming a certain ratio of growth. In the ratio diagram a forecast is made by simply drawing a straight line or extending a line already drawn to represent the rate experienced in the past. Equal rates of growth on a ratio diagram are clearly shown by parallel lines. We can move a curve bodily for comparison with another without impairing its value which is not permissible on a difference diagram. The best that can be said for the difference method is,

it always shows whether there is an increase or decrease. The base or zero line gives a means for comparing positive and negative quantities and for seeing in a simple and self-evident comparison the vertical elevations of points in a curve above or below the base line.

The features of a curve which most catch the eye are concerned with comparative direction. The eye reads a ratio chart more rapidly than a difference chart or a table of figures. What most catches the eye is enumerated as follows:

1. If we see a curve ascending and nearly straight we know that that statistical magnitude it represents is increasing at a nearly uniform rate.
2. The reverse for descending.
3. If the curve bends up the rate of growth is increasing.
4. If the curve bends down the rate of growth is decreasing.
5. If the direction of the curve in one portion is the same as the direction in some other portion it indicates the same percentage rate of change in both.
6. Steeper in one portion than another indicates more rapid rate of change.
7. Two curves parallel represent equal percentage rates of change.
8. If one is steeper than another the first is changing at a faster percentage than the other.
9. Imaginary straight line most nearly representing to the eye the general trend of the curve is its growth axis and represents the average rate of increase or decrease and deviations of the curve from this line are plainly evident without recharting. The preceding relates to direction. As to elevation the eye can with a little familiarity translate vertical elevation into numerical ratio, for a certain elevation represents a 10 per cent increase, another a 100 per cent increase.

As examples of the value of ratio diagrams, take a difference plot of millions of population over a period of 70 years by tens.

Figure 23 shows both a difference scale (A) whose vertical distances are equally spaced and equally marked and a ratio scale (*B*) with equal vertical spacing but with a marking corresponding to a constant increase of 10 per cent. Uniformity in percentage of growth is represented by a straight line. It is more convenient to use a log scale whose spacing is according to a percentage rate than to figure the proper marking for lines equally spaced.

The contrast then between the ratio and ordinary difference diagram is simply one of spacing, the ratio method having the numbers 1:10, 100:1,000 equally spaced. Another example of the false comparison of two curves by the difference method and

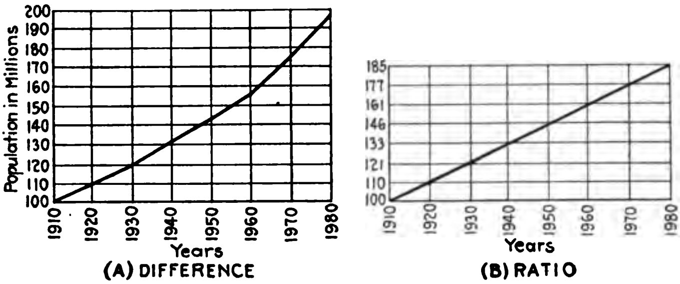
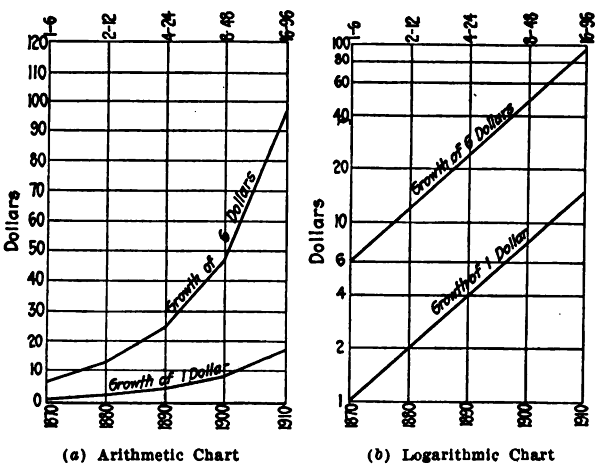


FIG. 23.—Comparison of difference and ratio plotting.

by the ratio method is shown in Fig. 24 (A) and (B). The growth of $1 and of $6 when placed at compound interest for 40 years does not look the same in (A) although the percentage increase is the same and so appears in the ratio diagram of (B)



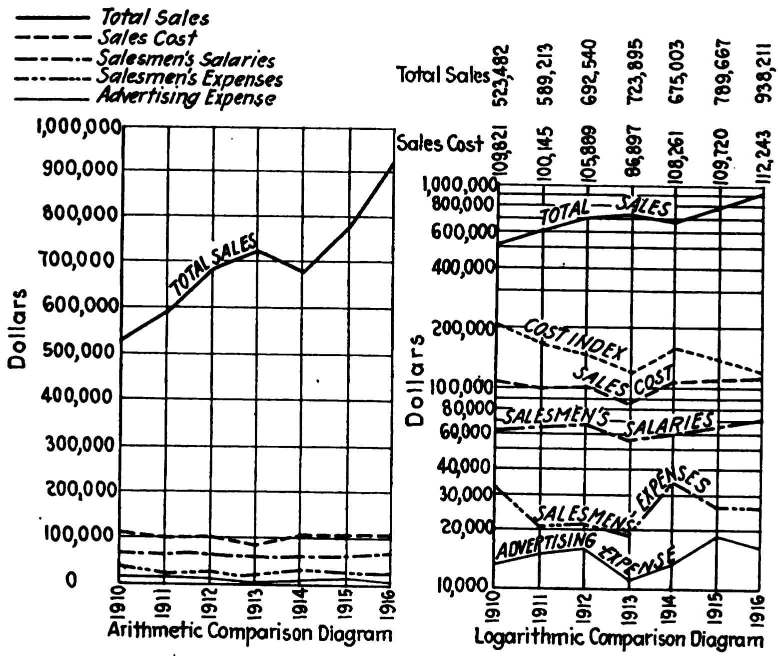
(a) Arithmetic Chart (b) Logarithmic Chart

FIG. 24.—Growth of 1 dollar and 6 dollars when placed at compound interest for 40 years. Comparison of two kinds of charts.

as the lines of growth are parallel. Another example of false comparison by the difference method is shown in Fig. 25(A). Here it appears as if the sales had risen tremendously in comparison with sales costs, whereas a plot on log paper in (B) shows

the sales cost and sales had not differed at any time very greatly in percentage. The table for plotting these diagrams is given below them.

If the data of a reference plot cause the graph to deviate continually from a straight line they may often be represented



Year	Total Sales	Sales Cost	Salesmen's Salaries	Salesmen's Expenses	Adverting Expense	Cost Index
1910	523,482	109,821	63,258	33,002	13,560	21
1911	589,213	100,145	65,212	20,830	15,103	17
1912	692,450	103,889	66,490	21,490	16,212	15
1913	723,895	86,897	57,211	18,556	11,130	12
1914	675,003	108,361	60,576	34,575	13,445	16
1915	789,667	109,720	65,110	26,021	18,589	14
1916	938,211	112,243	70,364	25,647	16,232	12

FIG. 25.—Comparison plotting of difference and ratio methods.

by an exponential equation of the form $y = mx^n$ where m and n are constants which may have any value. To test the numerical values of m and n we may use logarithmic paper and plot logs of x as abscissas and logs of y as ordinates. Writing $y = mx^n$ in logarithmic form gives $\log y = n \log x + \log m$.

Putting $x' = \log x$ and $y' = \log y$ and $b = \log m$ the equation becomes $y' = nx' + b$ which is the equation of a straight line. By using logarithmic paper we can locate points such as x and y proportionally to their logs and obtain a straight line as noted above.

The chief problems in the technique of historigram plotting are those of base line scales, types of lines to use for the graphs and methods of and purposes of smoothing these curves. The size of page, ability of grasp by the eye, subsequent treatment of the illustration, etc., are determining factors. The variable factor is usually plotted from a base line along the ordinate axis. Spacing and rules for scales apply as in frequency diagrams. When two or more curves are shown on the same diagram it is sometimes neccessary to adjust the scales to bring the curves nearer or farther apart. One method of scale conversion when the absolute differences are great is to equate the scales on the basis of their respective averages. Another method is to plot the curves of differences between the items and their averages. This is more of a mathematical method which does not appeal to the average business man. A more common method is to convert the individual variables into percentages of a total and express them in the form of index or relative numbers. Measurements on successive ordinates must be made from the base line and not from the tops of preceding ordinates. When related series are plotted on the same sheet they should be designated by similar markings. Lines should be broad enough to be easily followed but not to sacrifice the accuracy of the ordinate unit.

Before plotting any data it is well to consider several points with regard to that data. Statistics are collected (1) for the purpose of testing the progress of a commercial undertaking, (2) for testing the success of an institution, (3) for collecting data for the solution of a social problem.

Some of the objects of statistical analysis are: census of population, vital statistics, trade and transportation, prices, wages, production, employment, income and capital, taxes and rates.

Nine rules are suggested by Mr. Bowley to guide the line of study and criticism of statistics. These rules are here given and an examination of them will show how they can be applied to other data than statistics.

1. Find the exact definition of the units which go to make the total. In every case the definition depends on the regulations

and methods of collection. As an example, what is meant by a farmer? By a room, in the census reports?

2. How far the persons or things grouped together in a total or sub-total are similar or how far the group is homogeneous. Thus, persons whose occupations are grouped under textile fabrics differ with respect to (1) sex, (2) age, (3) nature of material worked (cotton, wool, etc.), (4) position in industry, as merchant, dealer, manufacturer or employee, (5) specific occupation, (6) locality.

3. Having defined and analyzed the totals, the next question is what is the relation of the quantity they measure to the quantity as to which we want knowledge?

4. Before trusting or even reading a statistical account it is well to sit down and think quietly what statistics ought to have been collected, if possible, for the purpose in hand and what sources of information exist or should exist. Having got so far we may consider how far the problem has been understood, whether all the practicable measurements have been made and whether the result gives a true index. We can thus decide as to whether the information is sufficient for solving any assigned problem.

5. When we have to deal with averages, rates and percentages we must carry our second rule of criticism further and consider not only if numerators and denominators are homogeneous in themselves but whether the terms of the denominator have a reasonable relation to those of the numerator. They should be limited to those cases which are so.

6. When two quantities are compared we must consider whether they are strictly comparable. Accurate comparisons can only be made between closely similar things or over quite short periods.

7. Closely related to the last is the measurement of accuracy. In all statistics we must decide whether the data and methods will yield results accurate enough for the arguments based on them.

8. We must not depend on figures relating to single days, months or years or on comparisons relating to short isolated periods. Where a sufficient record cannot be obtained, judgment must be suspended.

9. Having determined as far as possible the exact purport and limitations of the statistics, consider to what conclusions they

lead or whether they are so imperfect that no conclusions can be reached without further investigations. Inferences are suggested and tested by the reported facts and a severely critical and logical analysis is necessary before the whole investigation leads on to some reasoned action.

Examples for Chapters II and III

1. Before plotting diagrams what information must be given and in what form? Illustrate by two examples.
2. Into what classes are graphs and diagrams divided? Illustrate each one.
3. Explain how to construct a diagram using two axes at right angles and coordinates.
4. What is an ordinate? An abscissa? Why are plus and minus signs used?
5. What are the governing factors in selecting the scales of a diagram?
6. Enumerate a few of the various kinds of ruled paper used in making diagrams, and state the advantages of them.
7. How can logarithmic paper be constructed? Arith.-log paper?
8. What are the governing factors in the selection of paper for plotting a diagram?
9. Where should the coordinate axes be located and how indicated?
10. How should lettering or figures be placed to facilitate reading them?
11. How should arrangement of grouping be treated as regards sequence of time, size of item or favorability of item?
12. What governs the form selected for graphically representing a fact?
13. When several happenings are shown on one diagram how are their graphs distinguished one from another?
14. In making graphs for comparison what important points must be considered?
15. What is a frequency graph? Historigram? Continuous series? Discrete series? Cumulative frequency?
16. What three elements are visualized in plotting a series of economic data?
17. Explain the "ratio" method of plotting and compare it with the difference method.
18. When is log paper used in preference to coordinate paper?

CHAPTER IV

APPLICATIONS

In the preceding pages the general subject of graphical methods has been touched in the abstract although in the chapter devoted to the making of diagrams, a few examples have been given of the practical applications of the method.

The simplest line diagram is one drawn to show the relation of two quantities such as millimeters and inches, Fahrenheit and Centigrade temperature scales, diameters and circumferences

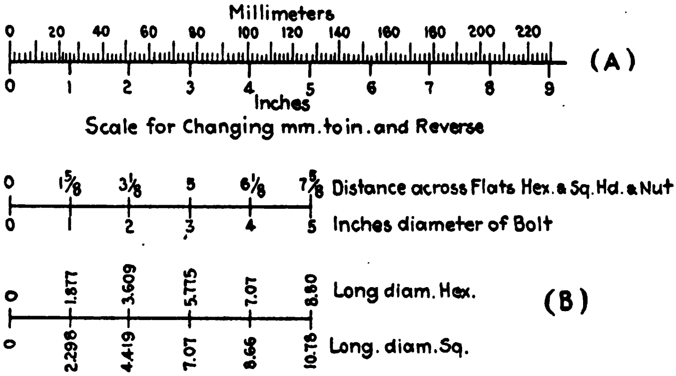


FIG. 26.—Conversion scales.

of circles, etc. These relations are expressed in tables as a rule, but often these tables require too much space or are not convenient to use on account of the interpolation required.

In Fig. 26(*A*) and (*B*) are shown two of the simplest of these line diagrams.

(*A*) is used to convert inches to millimeters or millimeters to inches. The spaces between the inch marks can be made any distance, the greater they are the greater the accuracy of the millimeter readings.

(*B*) is used to obtain the values of the distance across flats of U. S. Standard bolt heads and nuts. The long diameters of hexagonal and square nuts and heads are given on the lower

scale. The values of the long and short diameters of bolt heads and nuts can be found in engineering handbooks and marked off at the proper points of the scale opposite the corresponding bolt diameters. If desired the scale can be made in the form of a rule and applied directly to the drawing of bolts and nuts.

An application of the above method is found in the change from arithmetical to percentage scales. If a line such as Fig. 27(*a*) is divided into equal divisions and they are marked 10, 15, 20, etc., starting at one end, we will have an arithmetic scale. If the lower line is marked according to a fixed percentage difference of 100 per cent between them we have a percentage scale 10, 20, 40, 80, 160, etc. When intermediate numbers are

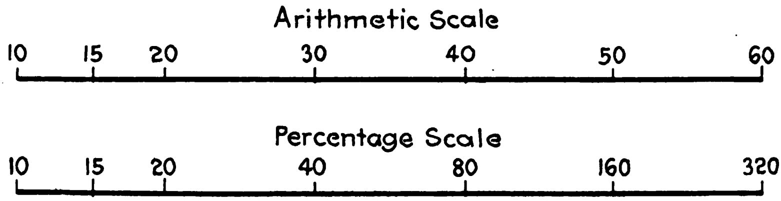


FIG. 27.—Comparison of arithmetic and percentage scale.

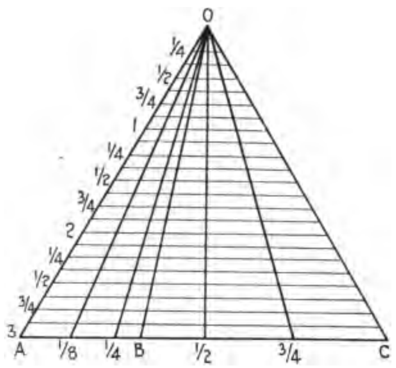
introduced between the numbers they will be spaced equally everywhere on the (*a*) scale but on the (*b*) scale the spaces will will be subdivided into more parts as we move to the right and the points of division will be closer together on account of the decreasing percentage of difference.

If we wish to locate the intermediate number 15 on the line (*b*) we find the log of 15 and locate the point according to the relation of the log of 15 to the logs of 10 and 20. When this is done the point 15 will be found nearer to 20 than to 10. It is this principle which is at the basis of the slide rule, the divisions being made according to the logs of the numbers marked on the rule. Paper can be obtained which is ruled according to this principle and called log-log paper Fig. 11 or arith.-log paper Fig. 26. A scale for finding the length of various proportions of the circumference of a circle when the diameter is given is shown in Fig. 28. If AB = the diameter of the circle its circumference will be equal to AC. If AC is subdivided into one-eighth, one-fourth, one-half and three-fourths of its length and these points joined to O, which can be taken at any convenient distance from AC, we can obtain the

same proportions of any circumference corresponding to the diameter given on the left-hand scale AO.

This replaces a table of six columns besides affording a ready means of taking off the dimension with a compass when it is desired for drawing a circle or subdividing a circumference.

A further application of diagram substitution for tables is found in Fig. 29. In this diagram one can find the inches of mercury, feet of air, pounds per square inch and atmospheres corresponding to feet of water, and *vice versa*, by erecting a perpendicular at the number of feet of water given, until it cuts the



GRAPHICAL METHOD OF FINDING CIRCUMFERENCE OF CIRCLE WHEN DIAMETER IS KNOWN

FIG. 28.

inclined line denoting the term required. A horizontal line through this point to the vertical axis will give the number corresponding to the feet of water given. This diagram replaces 15 tables and takes up very little space. Such diagrams are called *conversion* diagrams and their application to simple problems can often be made with benefit depending on the tables displaced and the economy of time resulting.

There is a type of problem which can be solved by a direct appeal to the eye which is extremely effective and simple. These problems are those involving time and speed such as, "If a man travels 5 miles in 1 hr., how far will he go in 5 hr.?" which is a simple one involving multiplication. Suppose, however, we have the following:

"A person walked from A to B at the rate of $3\frac{1}{2}$ miles per hour and then part of the way back from B to A ran at 7 miles

per hour and finished the remaining distance in 5 min. at the original rate. His total time was 25 min. A second man walks from B to A at a uniform rate and was also gone 25 min. At

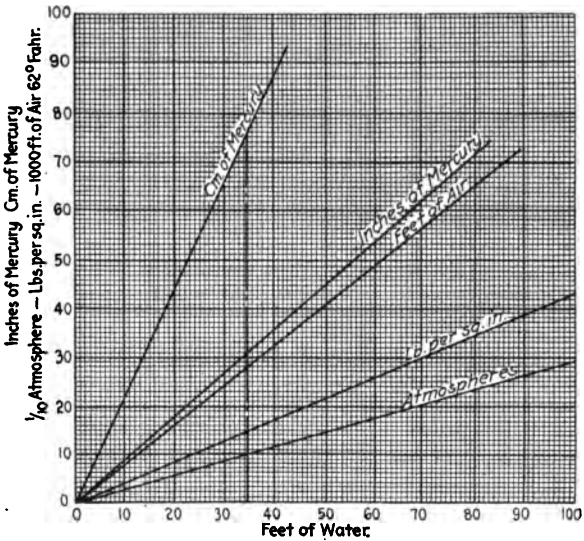


DIAGRAM FOR CONVERTING FEET OF WATER INTO ATMOSPHERES, LBS. PER SQ. IN., FEET OF AIR INCHES OF MERCURY & CENTIMETERS OF MERCURY

FIG. 29.

what two times will he meet the first man and how far from A will the two places of meeting be?"

Here is a case where simple multiplication will not answer, but by the graphical method it is nearly as simple as the first

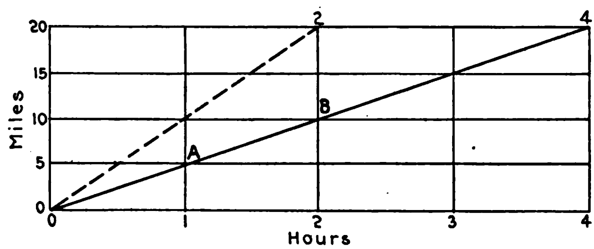


FIG. 30.—Diagram of distance *vs.* time.

example. The first example is solved thus: Draw a horizontal line and divide it into equal parts as at 1, 2, 3, 4 in Fig. 30. Let these represent hours. Through each of these points draw

vertical lines and on the verticals lay off equal divisions as 5, 10, 15, 20 to represent miles, and through these points draw lines parallel to the lower horizontal. If the man travels 5 miles in 1 hr., his path will be represented on the diagram by the line from 0 to A. If we wish to know how far he will go in 2 hr. we find B where the vertical through 2 cuts the diagonal 04. A horizontal through B cuts the vertical scale of miles at 10. For any other time the same procedure gives the answer on the left-hand scale of miles. If a second man goes twice as fast as the first his path will be shown by the more steeply inclined line from 0 on the base line to 2 on the highest line. Taking the second example let us apply the same principles.

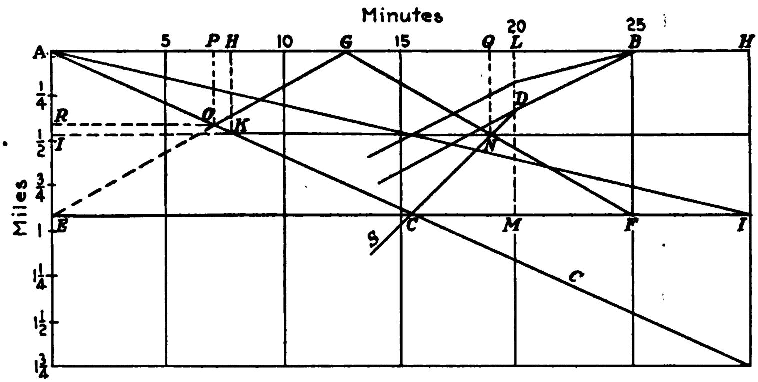


FIG. 31.—Solution of problem by graphical means.

In Fig. 31 take AB = 25 min. Lay off AH = same fraction of an hour that AI is of $3\frac{1}{2}$ miles. AK will then by its inclination represent $3\frac{1}{2}$ miles per hour. Produce this diagonal indefinitely toward C. Lay off BL = 5 min. on the time scale. Draw the vertical LM and the diagonal BD having the same slope as AC. From D draw a diagonal DS having the slope corresponding to 7 miles per hour with the same scales as those used for AC at $3\frac{1}{2}$ miles per hour. This diagonal intersects AC at C and the perpendicular distance from C to AB is the distance from A to B. The distance he ran was DM. If the second man starts from B and walks at a uniform rate from B to A and back and takes 25 min., his path will be represented by EG-GF. He will meet the first man at O the first time and at N the second time. The distances from A will be the vertical distances OP and QN. The times from A will be AP and AQ respectively.

These examples involve time and space but the same principle can be applied to questions of time and work done such as labor performed by men or machines, water discharged by pipes, etc. Questions in alligation may also be solved by the graphical method.

The application of the graphical method as outlined above to the adjustment of the running times of railway trains works out as follows: In Fig. 32 the spacing of vertical lines are hours, and horizontal lines are stations A, B, C, etc., at distances apart according to a vertical scale of miles. Suppose we wish to

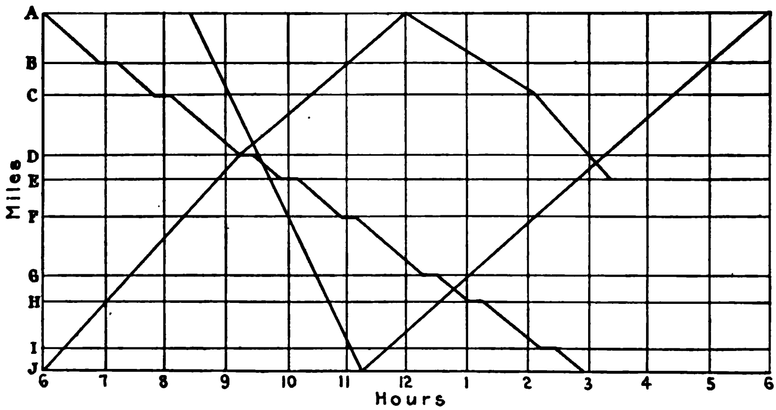


Fig. 32.—Train chart.

start a train from A at 6 A.M. to arrive at J at 3 P.M. with 15-min. stops at each station. Taking out eight stops of 15 min. each equals 2 hr. Therefore the train would reach J at 1 P.M. if there were no stops. The slope of the speed line will be found by joining A at 6 A.M. with J at 1 P.M. Draw this line from A to B, then move along B for 15 min. and draw a parallel to the speed line from B to C. Repeat this operation until the last diagonal line drawn from I cuts J, which it should do at 3 P.M.

If we start a train from A at 8:30 A.M. to reach J at 11:15 A.M. without stops, its path would be a continuous straight line from A to J, intersecting the path of the first train at D where it would meet it. Trains running in opposite directions are shown by diagonals ascending from left to right. Thus a train leaving J at 6 A.M. and arriving at A at noon is shown by a broken diagonal meeting the 6 A.M. and 8:30 A.M. trains at D.

The change in slope shows that the train runs faster from D to A than from J to D. If a train leaves A at noon running toward J, leaving C at 2:05 and reaching E at 3:20 and another train leaves J at 11:15 A.M. and G at 1 P.M. running to A as by diagram without stopping, the trains will pass at 3:10 P.M. between D and E at an exact point whose distance can be found by the scale of miles, therefore a siding must be built.

In practice the diagram is accurately drawn to a large scale and the several trains are represented by different colored elastic

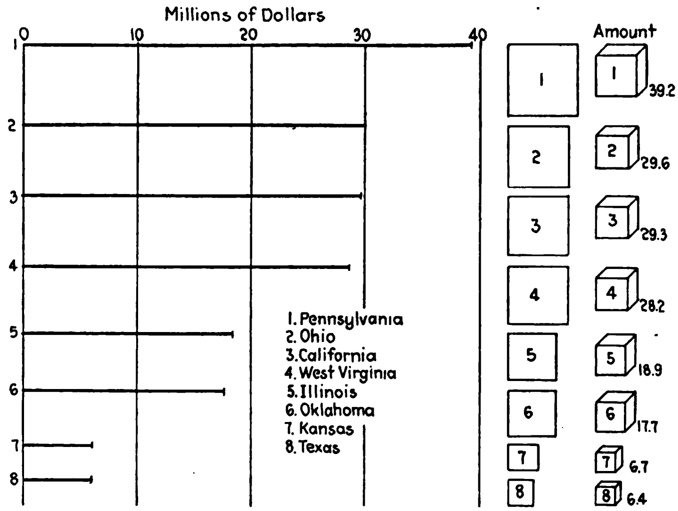
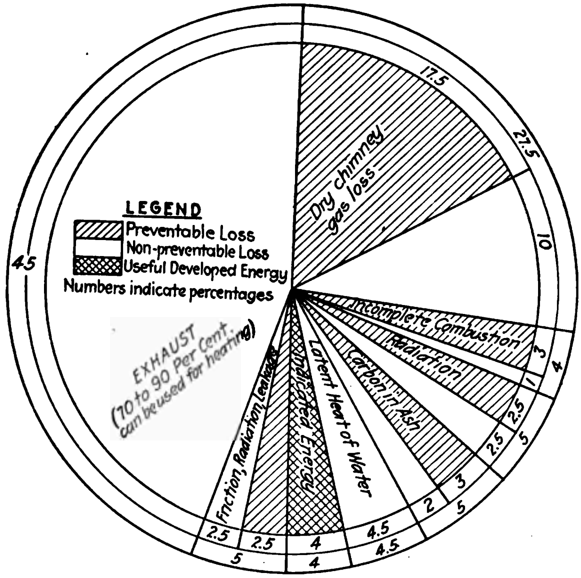


FIG. 33.—Comparison of lines, areas and volumes.

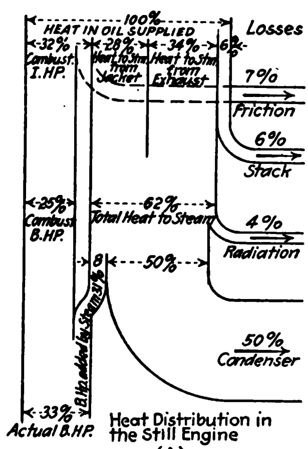
strings fastened by pins to enable schedules to be changed when necessary through accidents or delays. Grades and curves may be shown on the line AJ and speeds determined more readily. On a double-track road there may be a chart for each track and diagonals in one direction only will appear on each diagram.

Diagrams most frequently used to illustrate frequency and magnitude alone are lines and bars. Some use has also been made of surfaces and volumes, but this is not recommended because of the difficulty of grasping more than one dimension by visual inspection. Surfaces vary as the square of their sides, and volumes as the cube of their edges. Figure 33 is drawn to



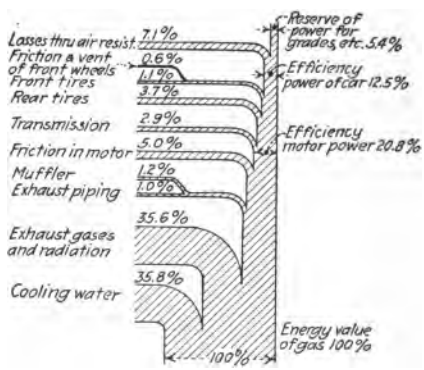
DISTRIBUTION OF HEAT LOSSES IN AVERAGE POWER PLANT OPERATING NON CONDENSING

FIG. 34.—Pie diagram.



Heat Distribution in the Still Engine

(A)



Energy Diagram 30 Hp. Car for Speed of 37.3 M. P. H. (Riedler)

(B)

FIG. 35.

show the comparison of lines, surfaces and volumes when dealing with magnitudes.

The lines show best to the eye and give an exact relation easily

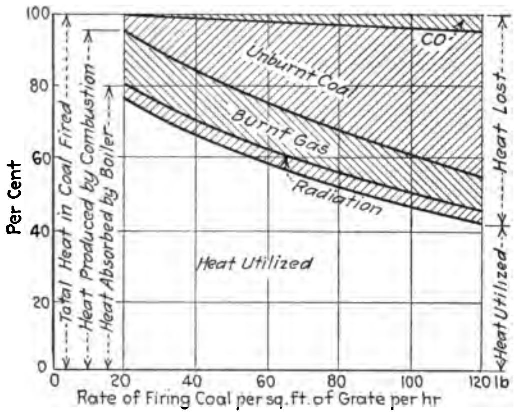


FIG. 36.—Percentage diagram.

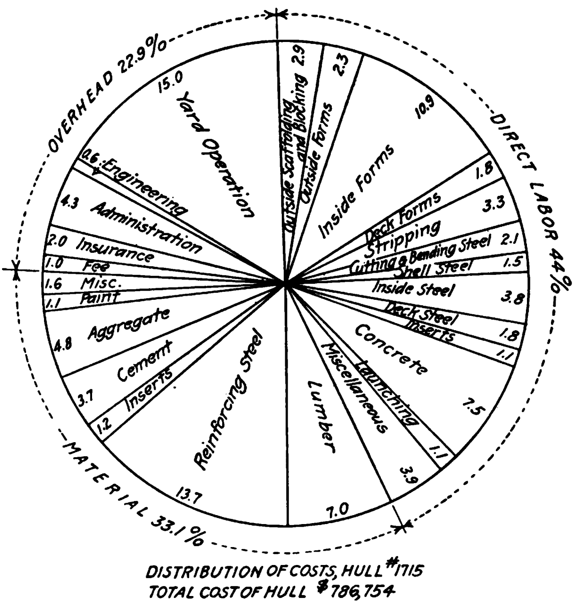


FIG. 37.—Pie diagram.

understood. Often a whole may be divided into parts by a pie diagram. The areas of the sectors have to be calculated and

the radial lines drawn to divide the circle into parts proportional to the percentages desired. Such a pie diagram for showing the distribution of heat losses in a power plant is shown in Fig. 34. The only excuse for such diagrams is the assumption that

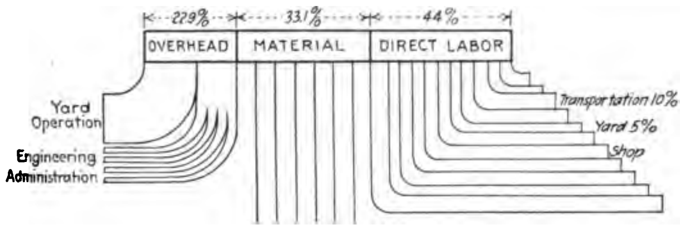
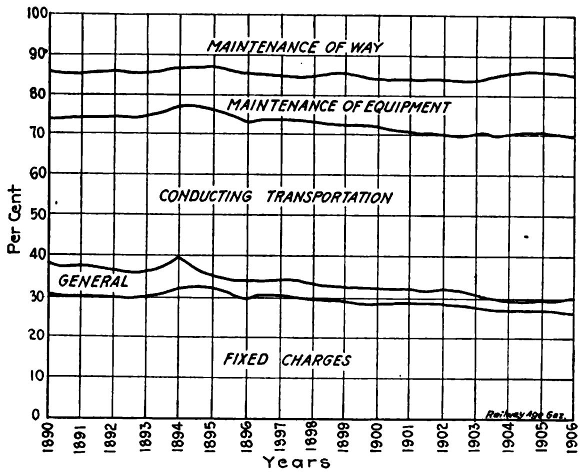


Fig. 38.—Alternate to Fig. 37.

the average mind grasps more quickly the fact that a circle represents 100 per cent, better than any other kind of a figure. The data illustrated here could be represented much better by means of such diagrams as Fig. 35, *A* and *B*, or Fig. 36. The construction is, moreover, much simpler.



PERCENTAGE DISTRIBUTION OF EXPENSES OF OPERATION OF R.R. OF U.S.

Fig. 39.

Pie diagrams cannot be readily compared without being superimposed. Figure 37 is a pie diagram which could have been shown in the form of Fig. 35 to much better advantage. Its appearance would then have been like Fig. 38. Distribution form for total to be used in preference to pie diagrams.

Figure 39 is a diagram used in statistical work to show the distribution of total expense cost over various departments for a term of years. The objection to this is the inability to show on it the actual totals without disturbing the symmetry of the diagram and making the top an irregular line to conform to the variation in yearly expense which would at once destroy the percentage scale line. A pie diagram for percentages of black, white, yellow, etc., of population in the United States in 1910 can

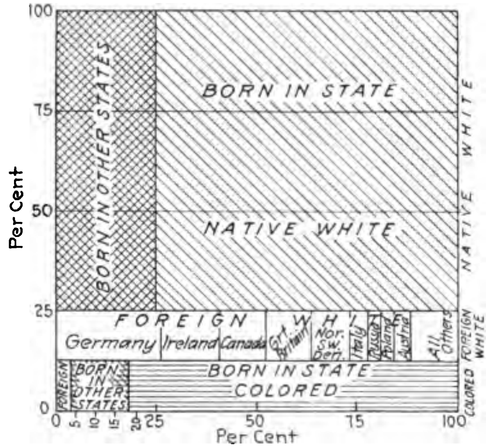


FIG. 40.—Population of U. S. in 1910.

be replaced to better advantage by a bar diagram like Fig. 40. Magnitudes must be drawn to scale and accompanied by their tabular values.

BAROGRAPHS

The vertical barograph can be used in cases where comparisons of several types are needed when all types have a common part and it is desired to show the relation of some characteristic of this part. As an example the comparison of the mean specific opening of valves on several types of automobile is shown in Fig. 41 by means of vertical bars. The unshaded portions of each bar are the ones to be compared. The superiority of the Bonz racing car over the Adler makes a strong impression on the eye. The figures confirming this fact and driving the point home are indicated at the base of each column.

The columns do not need to be so wide as the comparison is simply one of length. The horizontal barograph is better for

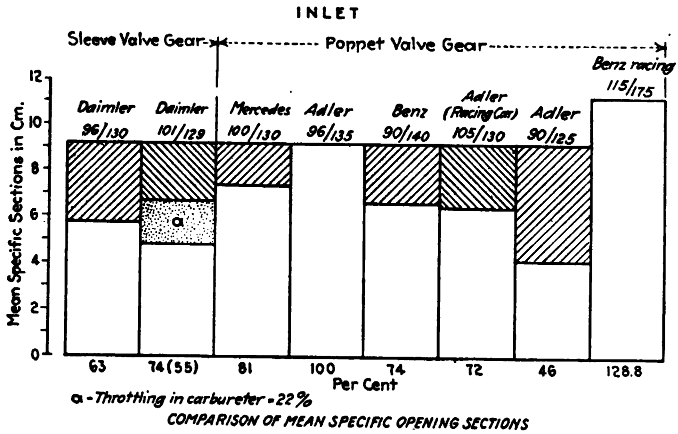


Fig. 41.

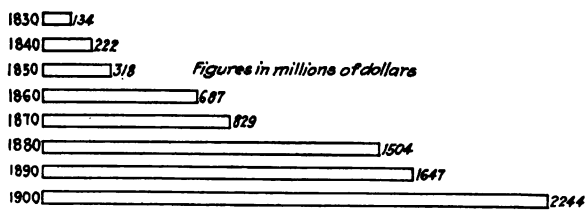


Fig. 42.—Values of exports from 1830–1900.

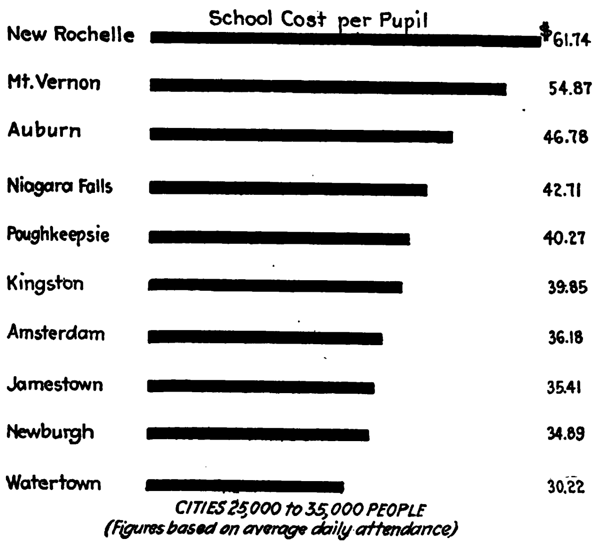


Fig. 43.

showing values of quantities by lengths of single lines or bars. The barograph is used most often for statistical representation although its application in shop production methods is rapidly

FIG. 44.—Occupational Intelligence Standards. Bar shows range of middle 50 per cent. Vertical crossbar shows position of median. Figure based on data from 36,500 men. Numbers at extreme left are occupational key numbers. Data taken from soldier's qualification cards.

gaining ground. The simplest form used is for showing increasing or decreasing phenomena over a period of time or a percentage value in a comparative way.

The value and growth of exports or imports over a term of years may be shown as in Fig. 42, but the advantage over a table is not so evident as to warrant the use of a diagram of this kind. A graph would be of much more value, especially if it was plotted according to a percentage scale. Fig. 43 is a barograph showing the school cost in different cities arranged according to order of

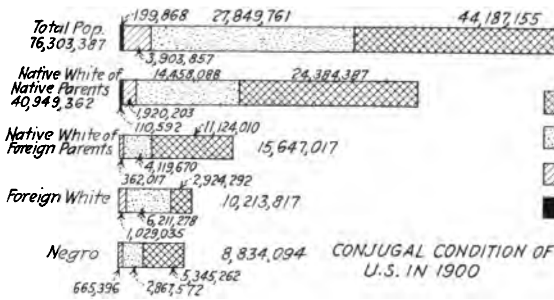


FIG. 45.

FIG. 46.

expense. The value would be increased if the same diagram gave population as well as cost per child in school. When the bars are broken off and the middle shown instead of the whole length we have a form of chart like Fig. 44. This is very unsatisfactory as there is no indication of the number of men examined in each class nor of the value of the standards *A*, *B*, *C* and *D*. There is no base line on the diagram which is most unsatisfactory.

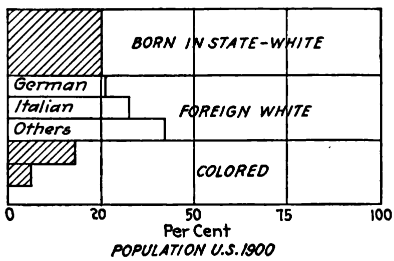


FIG. 47.

A horizontal barograph which shows data clearly but is not complete is the one shown in Fig. 45. Here we find the proportionate number of people according to their conjugal condition arranged in bars whose overall length varies so that comparison of relative per cent of married whites and negroes is impossible. If the bars were equal in length and that length equal to 100

per cent, the comparative proportion of each could be easily seen. A diagram giving such a comparison would be like Fig. 40. This also can be improved to a limited extent by making it as shown in Fig. 47 which enables a comparison to be made, to the same scale, of Germans, Italians and other foreigners.

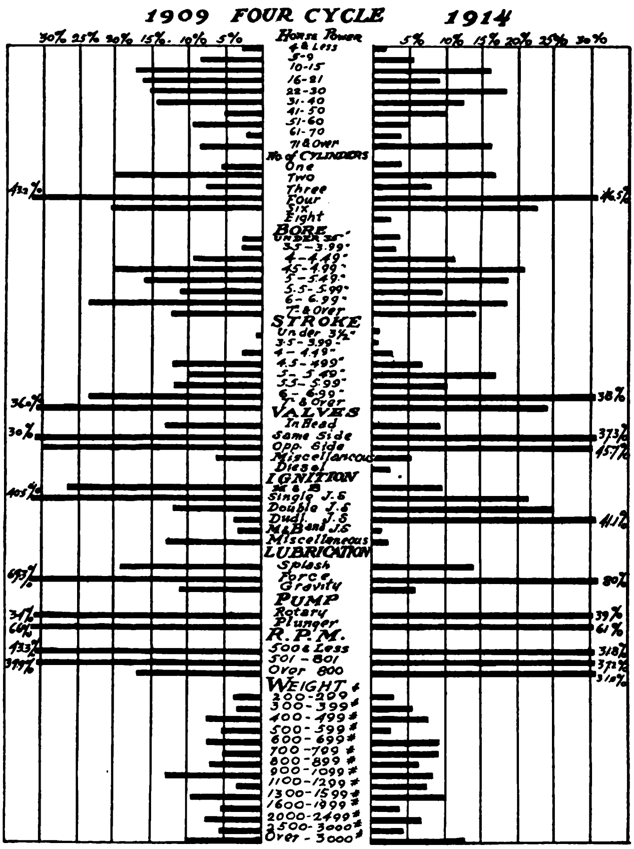


FIG. 48.—Changes in characteristics of marine motors from 1909 to 1914.

A method of using horizontal bars, which is not to be recommended, is shown in Fig. 48. This does not facilitate comparison of the bars on opposite sides of the center. If the bars were placed on one side only, the effect on the eye would serve to emphasize the facts, because the bars for the years would be side by side. Such an arrangement is shown in Fig. 49. This

method of comparison can be applied to three or more types of object, each one having the same component phenomena but varying in degree, by using as many bars side by side as there are objects compared. Each bar is cross-sectioned the same, for its own object in the bars under the different headings. As

FIG. 49.—Same as Fig. 48, with all data on one side for easy comparison.

an example of this the division of motor truck costs for three sizes of trucks is shown in Fig. 50. This shows how the size of truck affects certain costs more than others, in a more convincing way than if it was given in tabular form.

Table I gives considerable data regarding costs of operating gasolene motor trucks and it will be found useful in the construction of various diagrams as well as for comparison with Fig. 50.

TABLE 1.—TOTAL COST OF OPERATING GASOLENE MOTOR TRUCKS AT VARIOUS DAILY MILEAGES

Capacity of truck	Cost in dollars	Horsepower	Miles per hour	Miles per gallon of gasolene	Daily mileage	Estimated life, years	Total mileage	Costs for entire life of truck, in dollars: Insurance, fire and liability	License and taxes	Interest at 6 per cent	Depreciation	Administration	Garaging	Gasolene at 16 cents per gallon	Oil, grease and waste	Tires (less first cost)	Driver's salary	Inspection and maintenance	Total	Cost per day, dollars	Cost per mile, dollars	Cost per ton-mile, dollars
Light delivery wagon	600	18	25	15	25	5	37,500	200	40	180	600	35	180	400	190	225	2,400	750	5,200	3.47	0.139	0.417
					50	2½	37,500	100	25	90	500	20	90	400	190	225	1,200	655	3,495	4.66	0.096	0.288
					75	1½	33,750	60	20	55	450	10	55	360	170	200	900	505	2,785	6.19	0.082	0.246
1,500 lb.	1,100	22	20	12	25	6	45,000	300	65	400	1,100	110	215	600	340	270	3,600	1,010	8,010	4.45	0.178	0.237
					50	3	45,000	150	50	230	950	55	110	600	340	270	1,800	900	5,455	6.06	0.121	0.161
					75	2	45,000	100	30	130	850	35	70	600	340	270	1,440	790	4,655	7.76	0.103	0.137
1 ton	1,875	24	19	8	25	10	75,000	850	220	1,125	1,875	225	480	1,500	560	1,340	7,200	1,900	17,275	5.76	0.230	0.230
					50	6½	97,500	550	140	730	1,690	140	310	1,950	730	1,800	4,680	1,900	14,620	7.50	0.150	0.150
					75	4	90,000	300	85	395	1,500	90	170	1,800	675	1,640	3,468	1,800	11,815	9.85	0.131	0.131
1½ tons	2,150	25	18	7	25	10	75,000	1,000	235	1,290	2,150	255	600	1,710	560	1,505	7,200	2,000	18,505	6.17	0.247	0.165
					50	6½	97,500	650	150	840	1,935	170	390	2,230	730	2,025	4,680	2,000	15,800	8.10	0.162	0.109
					75	4	90,000	350	95	450	1,725	100	210	2,055	675	1,850	3,360	1,900	12,770	10.64	0.142	0.095
2 tons	2,625	26	17	6	25	10	75,000	1,150	265	1,575	2,625	315	720	2,000	750	1,840	7,200	2,250	19,440	6.90	0.276	0.138
					50	6½	97,500	750	195	1,025	2,360	205	470	2,600	975	2,475	4,680	2,250	17,985	9.22	0.184	0.092
					75	4	90,000	400	110	550	2,100	125	250	2,400	900	2,255	3,360	2,100	14,550	12.12	0.162	9.081
3½ tons	3,500	32	14	5	25	10	75,000	1,350	380	2,100	3,500	415	960	2,400	750	2,345	9,600	3,250	25,700	9.02	0.361	0.103
					50	6½	97,500	875	245	1,365	3,150	270	625	3,120	975	3,150	6,240	3,250	23,265	11.93	0.239	0.068
					75	4	90,000	460	150	735	2,800	165	335	2,880	900	2,870	3,840	3,000	18,135	15.11	0.201	0.057
5 tons	4,600	35	12	3½	25	10	75,000	1,760	440	2,760	4,600	550	1,200	3,430	750	2,680	10,800	4,000	32,970	10.99	0.439	0.088
					50	6½	97,500	1,145	285	1,845	4,140	360	780	4,460	975	3,600	7,020	4,000	28,610	14.67	0.297	0.059
					75	4	90,000	600	180	965	3,680	220	480	4,115	900	3,280	4,320	3,600	22,340	18.62	0.223	0.044
6½ tons	5,000	40	10	3	25	10	75,000	1,875	525	3,000	5,000	590	1,320	4,000	940	3,015	10,800	5,000	36,065	12.02	0.481	0.074
					50	6½	97,500	1,220	350	1,950	4,500	380	860	5,200	1,220	4,050	7,020	5,000	31,750	16.35	0.326	0.050

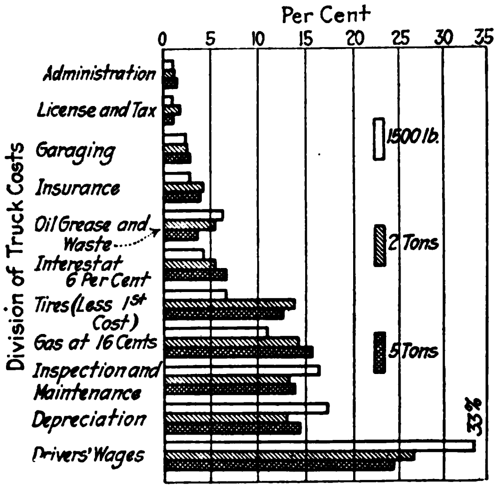


Fig. 50.—Truck operating costs. Comparison of 3 sizes, 1500 lb., 2 ton and 5 ton.

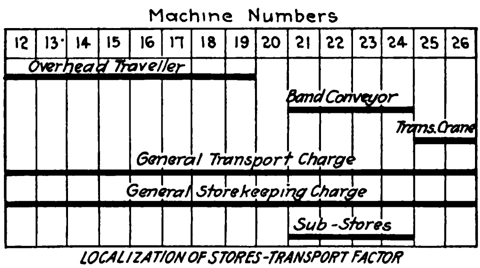


Fig. 51.

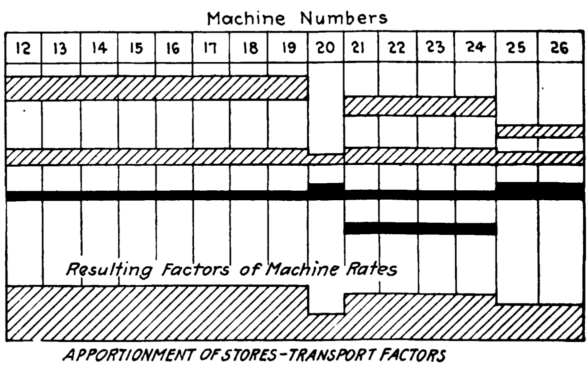
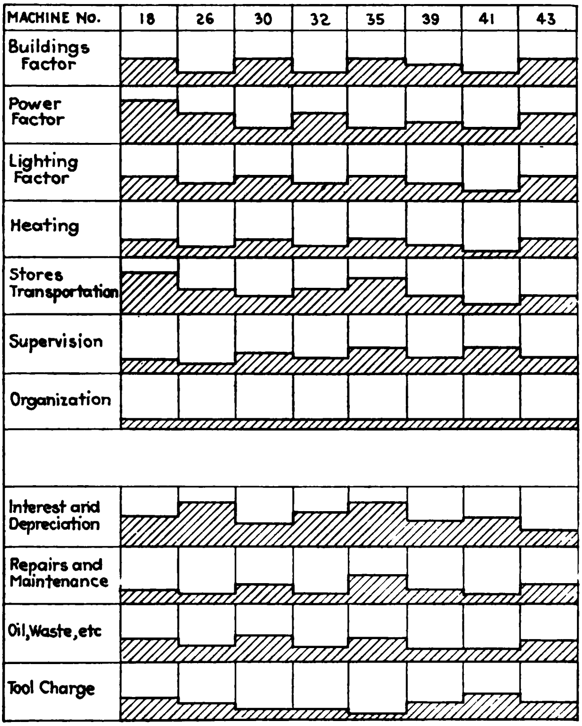


Fig. 52.

A method of apportioning costs by barographs is often used in showing to what machines charges are to be made. For example, the cost of transportation of stores or parts in a shop must be prorated among the various machines. A diagram is laid out like Fig. 51, the numbers at the tops of the columns representing certain machines. The horizontal lines show how the costs



RELATIVE ABSORPTION OF FACTORS BY THE DIFFERENT PRODUCTION CENTERS IN A SHOP

FIG. 53.

of certain systems of transporting parts are allocated to the different machines. The total cost of transportation for each machine will consist of the sum of the various items in that machine column. This diagram is better illustrated by drawing the width of the horizontal lines to scale as in Fig. 52, the line at the bottom representing the total cost of transportation for each machine, when measured by a vertical scale.

When a diagram for each item of cost has been worked out in this manner they can be added together as in Fig. 53, having first

been drawn to scale for each item. Any excess or unequal costs can be quickly detected from this diagram which a table would not easily reveal.

Factors above the blank space are overhead and those below belong to each individual tool. If plotted to scale, the vertical sum of horizontal lines in each column would give total expense due to each factor.

As a further illustration of the use of barographs, two figures are shown of the results of tests on oil made before using it and

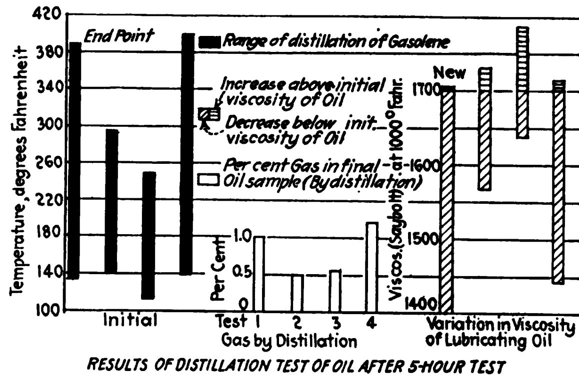
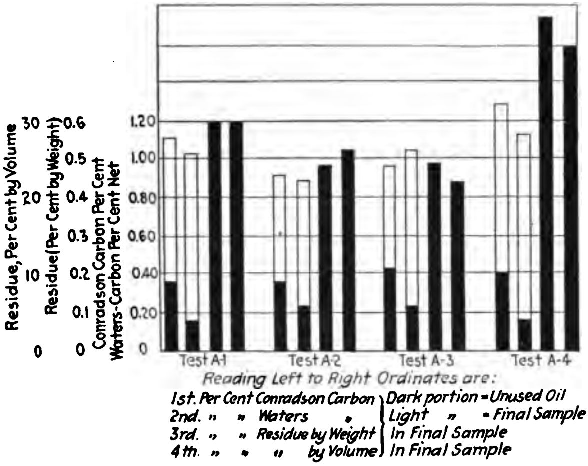


FIG. 54.

after a 5-hr. test. If these two diagrams, Fig. 54 and Fig. 55, had been combined in one, the comparison of the four oils could have been more easily made than now where the eye has to change from one to the other. A comparison of tabular presentation and graphical may be made by referring to Fig. 56 which is one of the simplest imaginable. There is room in this case for some question as to whether or not the graphical illustration is any clearer than the table, besides being harder to make.

The principle of showing production by the horizontal barograph is a good one as additions from day to day can be readily made. For example, in Fig. 57 consider several parts *A*, *B*, *C*, and *D* in process of manufacture and shipment. A report is desired each week showing the per cent actually finished and shipped. The solid bars show the amount finished and the blank bars the amount shipped. The second week the increment completed is cross-hatched while the quantity shipped is

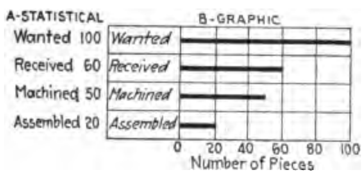
shown by a continuation of the blank bar with a vertical line for the end. The third week the bar increment of production is black again. The numerals at the ends of the increments denote per cent completed. If this is made on tracing cloth a print can



RESULTS OF TEST SHOWING VARIATION OF CARBON CONDITIONS IN 4 SAMPLES OF NEW OIL

FIG. 55.

be made each week which will show by comparison with the previous week the quantity produced and shipped that week. This method is continued until all the parts have been shipped. This principle can be easily adapted to include the material and operations noted in Fig. 56, by making the bars of greater width. It is not advisable, however, to crowd too many things into one



COMPARISON OF GRAPHICAL & STATISTICAL PRESENTATION

FIG. 56.

diagram and extensions of this method must be left to the judgment of the executive who uses them.

The bar method has been applied to diagrams illustrating the movement of railway cars, lighters or towboats by assuming the

time element along the horizontal and cross-hatching the bar to illustrate what was going on at the different periods of the day. Such a diagram is shown in Fig. 58. By means of daily reports

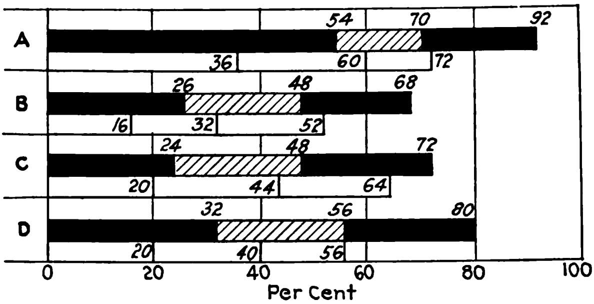
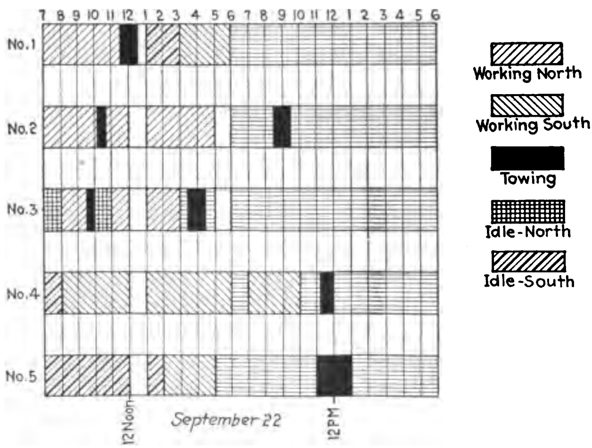


FIG. 57.—Manufacturing progress report.

of this kind it is easy to note any undue delay or extraordinary occurrence by a simple glance at the diagram. This can be applied to the movement or operations of motor trucks, operatives, horse trucks, freight cars, cranes, etc.

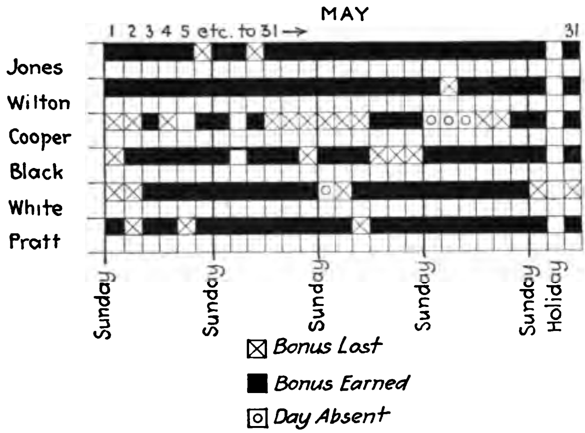


OPERATION OF FREIGHT LIGHTERS, N.Y.

FIG. 58.

The application to operatives has been well worked out by many efficiency engineers to show bonus payments and attendance. This is shown in Fig. 59 which is taken from Mr. Gantt's book on "Industrial Efficiency."

A similar use is made in Fig. 60 of this method in showing the rating of different states from the point of view of attendance and other features in schools, by varying the relative position

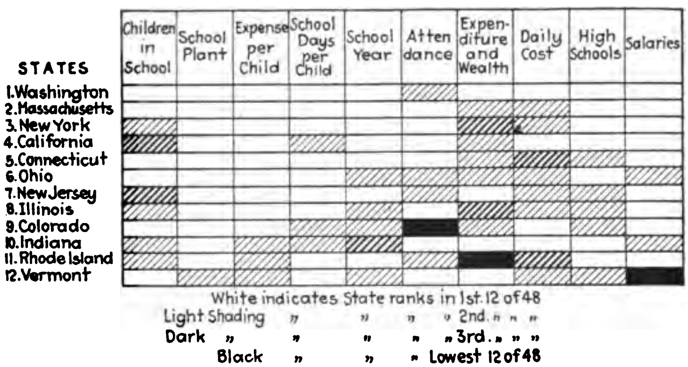


RECORD OF WORK IN A MILL

FIG. 59.

of the states. The diagram is taken from W. G. Brinton's book on "Graphic Methods."

A field which is adapted to the horizontal bar method but so



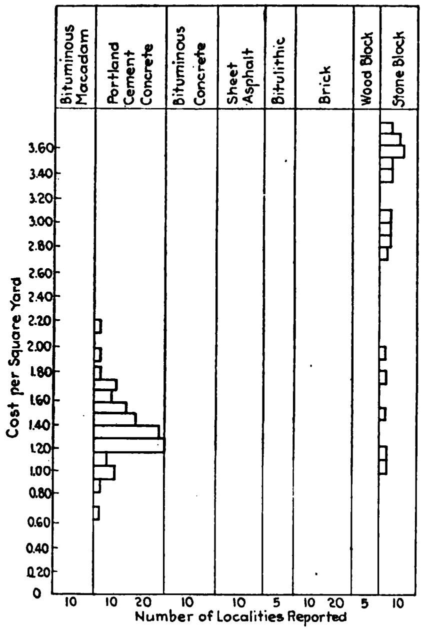
RANK OF STATES IN EACH OF 10 EDUCATIONAL FEATURES IN 1910

FIG. 60.

far without many examples of its value, seems to be that of showing comparative costs and their frequency as well. The application to pavement costs and variation of the cost of different

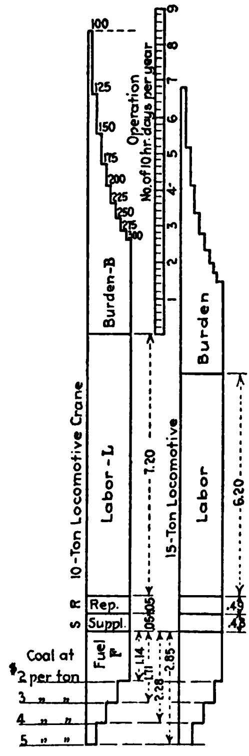
kinds of pavement is shown graphically in Fig. 61. The comparative cost of operating cranes of different sizes and the variation of this cost depending on days operated, cost of coal, etc., is shown in Fig. 62 by the barograph type of diagram.

In the same class as Fig. 61, combining the bars with a frequency diagram, is Fig. 63 showing the classification of overhead



RELATIVE AMOUNT AND COST OF PAVEMENT CONSTRUCTION IN 1915

FIG. 61.

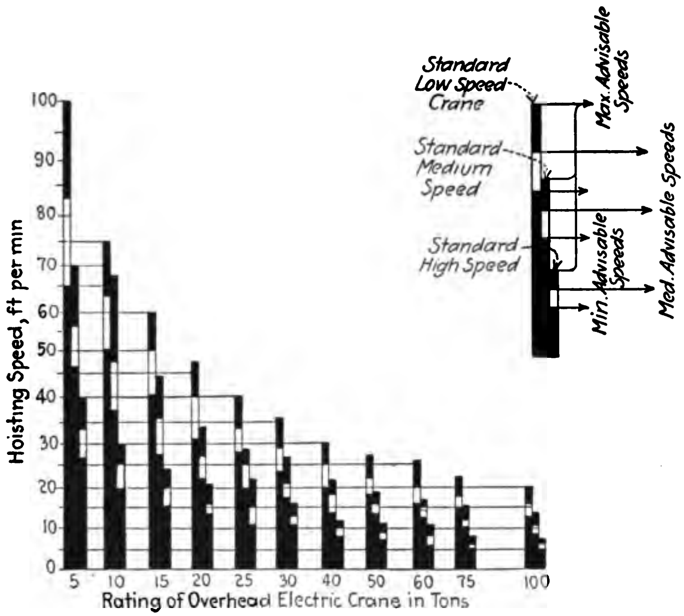


AVERAGE BASIC OPERATING COST OF STANDARD LOCOMOTIVE CRANES

FIG. 62.

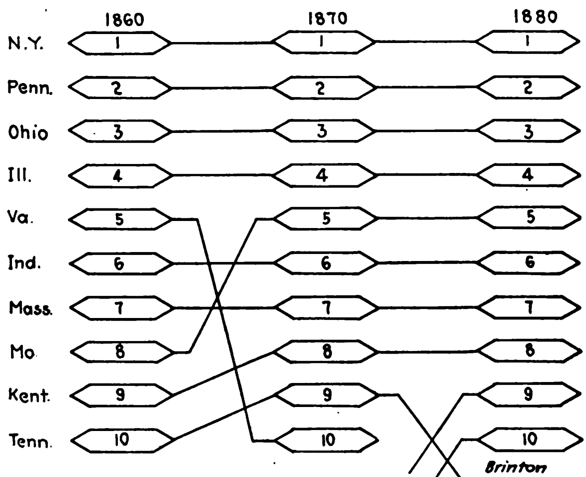
electric cranes by capacity together with their hoisting speeds which divide each class into three others. The width of bar allows three divisions along the X-axis to represent high, intermediate and low-speed cranes.

An unusual type of representation is shown in Fig. 64. This can be placed in the bar class although the lines showing move-



MAXIMUM, MEDIUM & MINIMUM HOISTING SPEEDS OF STANDARD OVERHEAD HIGH, MEDIUM & LOW SPEED ELECTRIC CRANES

Fig. 63.



RANK OF STATES IN POPULATION AT DIFFERENT CENSUS YEARS

Fig. 64.

ment bring it more in the routing diagram class. It shows plainly how a state changes rank from decade to decade but does not denote the number of the rank after the first census year indicated. By following back from later columns to the first one its position number can be ascertained easily and compared to its position in 1860 which is always carried along with the progressive movement.

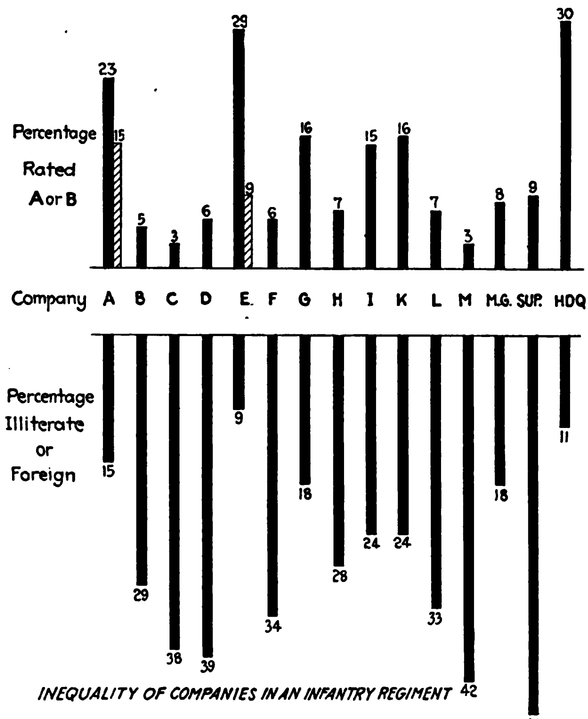


FIG. 65.

The bar method finds an important place in the analysis of any mental tests in two examples shown in Figs. 65 and 67. In Fig. 65 the diagram can be greatly improved for purposes of comparing illiteracy and high mental efficiency by placing all bars above or below the line of company designation and cross-hatching the illiterate bars as shown in the cases of Co. A and Co. E. The number examined in each company should also be indicated unless it is the same and then a note should so state.

Figure 66 is open to the criticism that no scale is given for comparing percentages nor is the percentage given for the classes. The only data given is that on the diagram.

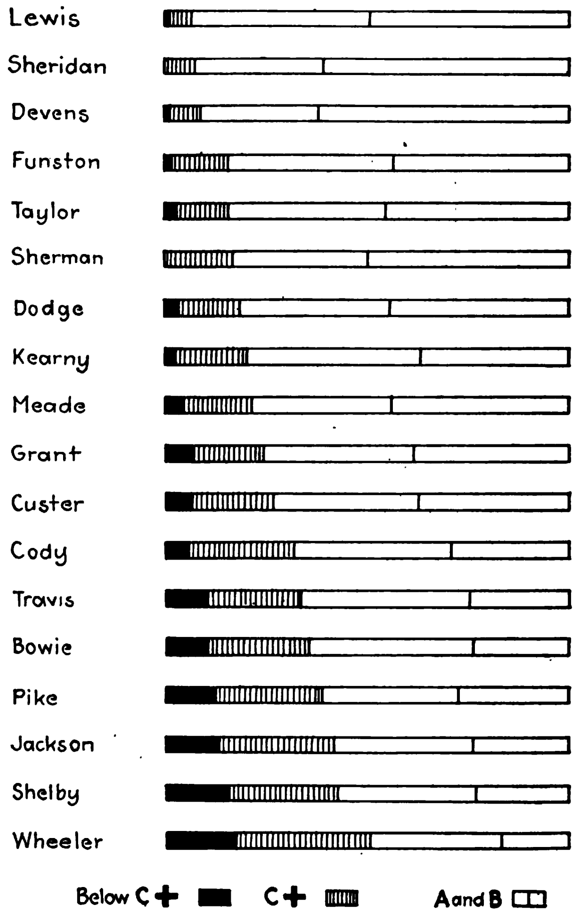


FIG. 66.—Inequality of mental strength in eighteen officer's training schools. (Total enrollment 9240.) The proportion of A grades in the above school varied from 16.6 to 62.4 per cent. The proportion of A and B grades combined from 48.9 to 93.6 per cent. and the proportion below C+ from 0 to 17.9 per cent.

FREQUENCY DIAGRAMS

Let us now take up the frequency and historical type of diagram, such as those used by statisticians and engineers to denote growth of population or relation of two or three variables. Such

diagrams as these are usually plotted on cross-section paper using rectangular coordinates. Through the points thus located a line is drawn which illustrates the law of change or the fluctuations and general trend.

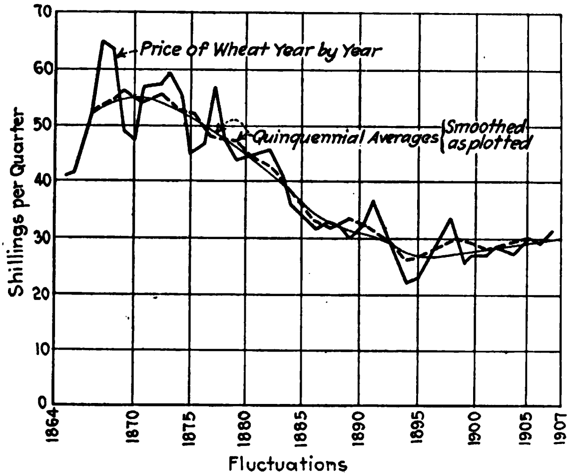


FIG. 67.—Variations in price of wheat in England 1864–1907.

Suppose a table gives the price of wheat annually and by 5-year periods (Table II). If we plot this table in Fig. 67 we will have a broken full line of the yearly changes, a dash and dot line for quinquennial averages and a smoothed line showing the

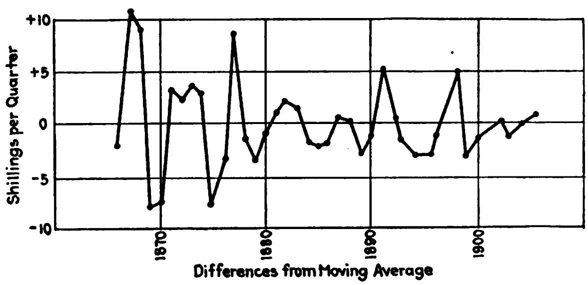


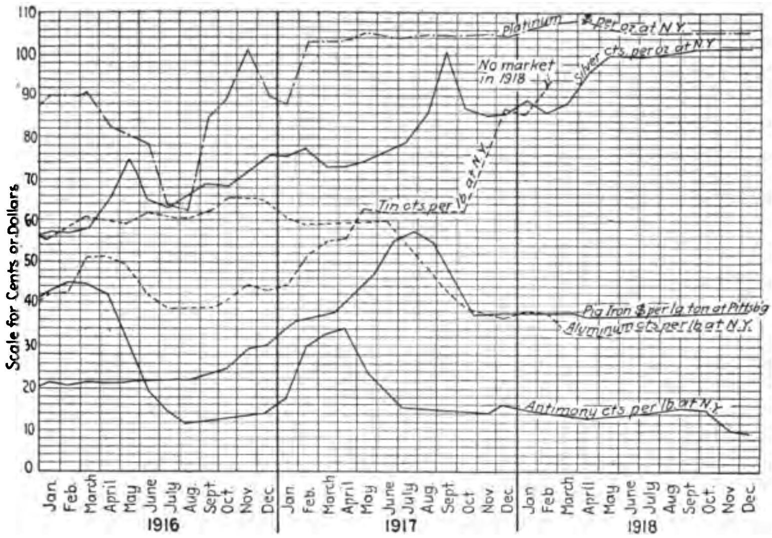
FIG. 68.—Variations in wheat prices.

trend or consequents. The difference between the price of a particular year and the average price of the 5 years of which that year is the middle are called differences and are plotted in Fig. 68.

TABLE II

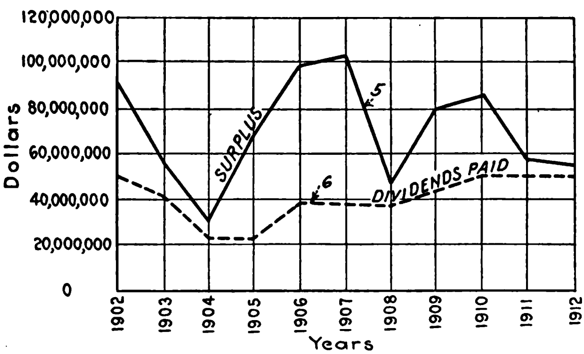
Average annual gazette price of wheat per quarter		Quinquennial averages		Difference
1864	40.2			
1865	41.8			
1866	49.9	1864–1868	52.0	– 2.1S
1867	64.4	1865–1869	53.6	+10.8
1868	63.7	1866–1870	54.6	+9.1
1869	48.2	1867–1871	56.0	–7.8
1870	46.8	1868–1872	54.5	–7.7
1871	56.7	1869–1873	53.5	+3.2
1872	57.0	1870–1874	55.0	+2.0
1873	58.7	1871–1875	54.7	+4.0
1874	55.7	1872–1876	52.6	+3.1
1875	45.2	1873–1877	52.5	–7.3
1876	46.2	1874–1878	50.0	–3.8
1877	56.7	1875–1879	47.7	+9.0
1878	46.4	1876.1880	47.5	1.1
1879	43.8	1877–1881	47.3	–3.5
1880	44.3	1878–1882	45.0	–0.7
1881	45.3	1879–1883	44.0	+1.3
1882	45.1	1880–1884	42.4	+2.7
1883	41.6	1881–1885	40.1	+1.5
1884	35.7	1882–1886	37.2	–1.5
1885	32.8	1883–1887	34.7	–1.9
1886	31.0	1884–1888	32.8	–1.8
1887	32.5	1885–1889	31.6	+0.9
1888	31.8	1886–1890	31.4	+0.4
1889	29.7	1887–1891	32.6	–2.9
1890	31.9	1888–1892	32.1	–0.2
1891	37.0	1889–1893	31.0	+6.0
1892	30.2	1890–1894	29.6	+0.6
1893	26.3	1891–1895	27.9	–1.6
1894	22.8	1892–1896	25.7	–2.9
1895	23.1	1893–1897	25.7	–2.6
1896	26.2	1894–1898	27.2	–1.0
1897	30.2	1895–1899	27.8	+2.4
1898	34.0	1896–1900	28.6	+5.4
1899	25.7	1897–1901	28.7	–3.0
1900	26.9	1898–1902	28.3	–1.4
1901	26.7	1999–1903	26.8	–0.1
1902	28.1	1900–1904	27.3	+0.8
1903	26.7	1901–1905	27.9	–1.2
1904	28.3	1902–1906	28.2	+0.1
1905	29.7	1903–1907	28.7	+1.0
1906	28.2			
1907	30.6			

A study of a graph of this kind enables the statistician to observe the variation of yearly price from the average over a period of years. Figure 67 is useful in its assistance in the determination of upward or downward tendencies over a period of



MONTHLY AVERAGES OF METAL PRICES 1916-1918

FIG. 69.



SURPLUS EARNED & DIVIDENDS PAID BY U.S. STEEL CORP.

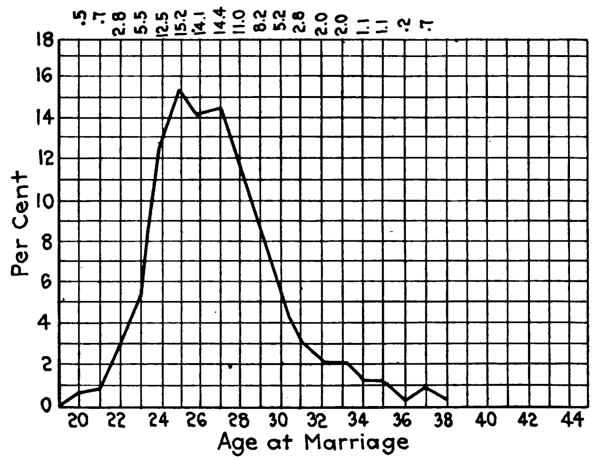
FIG. 70.

years even though the yearly variation presents no definite trend from year to year.

A similar diagram is shown in Fig. 69 containing the fluctuation price curves of several metals. The prices are given in such

a way as to bring the curves apart, yet do not prevent easy comparison of the fluctuations from month to month over a period 3 years. The trend of silver prices is seen to be upward while antimony tends to decline.

The amount of earnings applicable to dividends and the dividend amount paid out by the U. S. Steel Corporation is indicated clearly in Fig. 70. A curve showing the surplus dividend fund increase could easily be added and would be illuminating to the average reader of such statistics. This would of



AGE AT MARRIAGE OF 439 MARRIED GRADUATES OF MT. HOLYOKE WHO GRADUATED FROM 1890 TO 1909

Fig. 71.

course be a cumulative curve and not a frequency or historical one.

A type of frequency curve often met with is shown in Fig. 71. This brings out startling facts which a glance at a table would hardly notice, such as the large number married at 25 years and the small number married after 33 years.

The occupations of engineering graduates of the University of Illinois up to 1916 is shown by diagram Fig. 72 more like a cumulative diagram than a frequency one. It serves rather as a table with diagram attachment and is but little clearer than the table alone. The arrangement followed in Fig. 71 would enable a percentage determination to be made which would give a better idea of the proportion in each line than shown in Fig. 72.

6

An excellent example of a graphical representation of statistical facts is that in Fig. 73, which is a study of the married conditions in the U. S. for the year 1900. A companion diagram for this

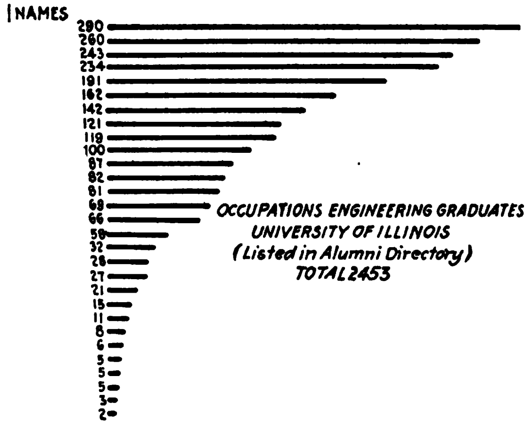


FIG. 72.—Occupations of graduates to 1916, (occupation names omitted).

would be one showing the excess of married over the single and widowed combined.

Figure 74 is a graphic record of the observations made in running an electric power plant for one month. The delineator

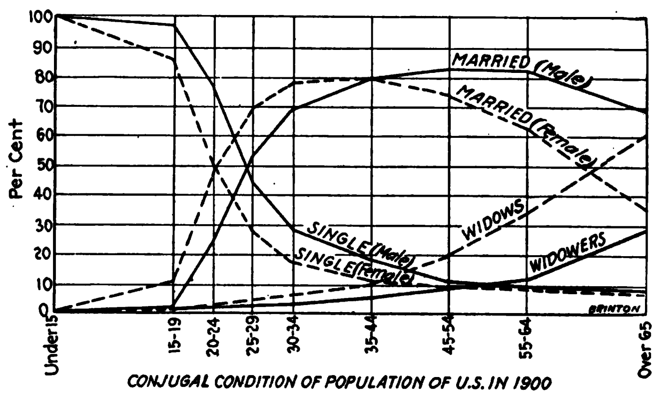


FIG. 73.

has here substituted vertical bars for coordinated points hence the broken appearance of the line usually called the "curve." This form is better for making comparisons from month to

month than the type shown in Fig. 69 and especially so if the plots are made on tracing cloth or paper. Then it is possible to

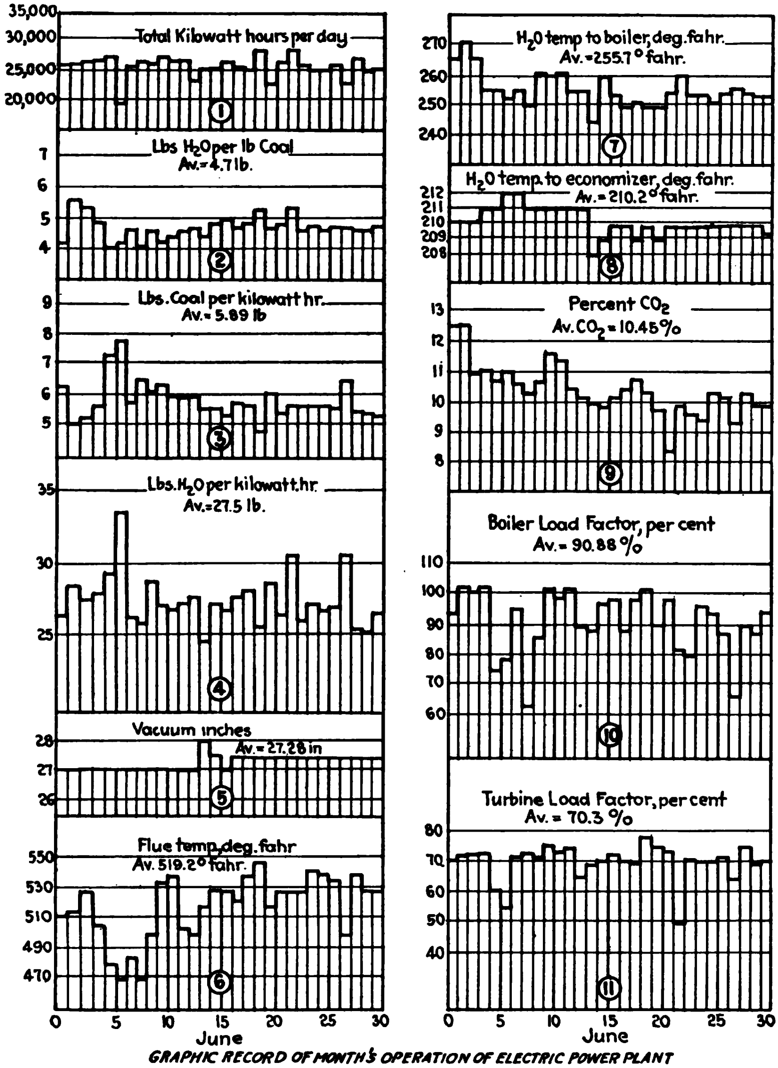


FIG. 74.

superimpose one month on another for purposes of comparison.

Figure 75 is an historical graph showing the development of the

hydraulic turbine. This combines several curves using different scales in one diagram but without any difficulty in its interpretation. There is no good reason for having two zero lines for the scales at the bottom and the zero line for efficiency should be indicated.

An example of the history of the financial standing of a public utility over a period of 57 years is shown in Fig. 76.

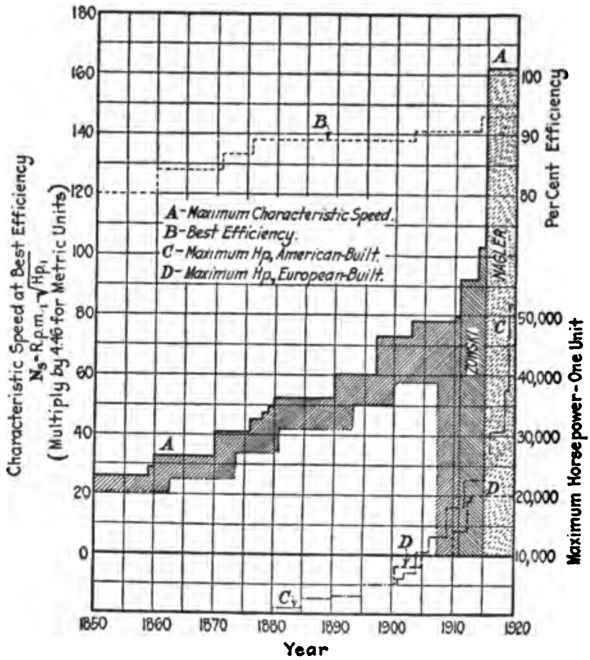


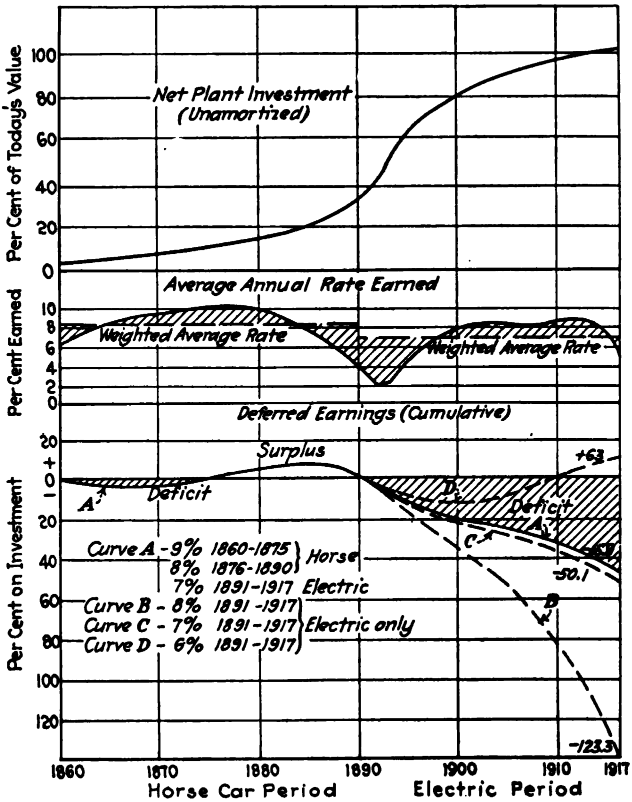
Fig. 75.—Representation of the development of the hydraulic turbine.

The position of the three curves is on a common base line of time. The base lines for the vertical scales are separated as in Fig. 74 but curves are used rather than vertical bars.

Two diagrams to illustrate rising prices for materials and wages over a period of years are shown in Fig. 77. (*A*) represents the increase on a basis of $100 in 1897 while (*B*) is based on a per diem wage in both 1899 and 1911. The increase in both (*A*) and (*B*) is shown by a straight line which is not true in either case. Intermediate years should have been used which would have made the cost lines appear like the lines in Figs. 75 or 69.

If the two years, 1897 and 1907, in (*A*) or 1899 and 1911 in (*B*) were the only ones used these diagrams would have been better in the form of barographs of two heights for each class of material or labor.

Figure 78 is a diagram to show the effect of training on the earning power of boys starting at the age of 16 years. This



INVESTMENT HISTORY OF A PUBLIC UTILITY

FIG. 76.

diagram should have had a vertical scale of wages per week either on the right or left hand margin also a horizontal scale denoting years elapsed since training began. The diagram would not then have been so covered with numerals and notes and would have been just as intelligible.

In Fig. 79 is found the application of diagram or statistical

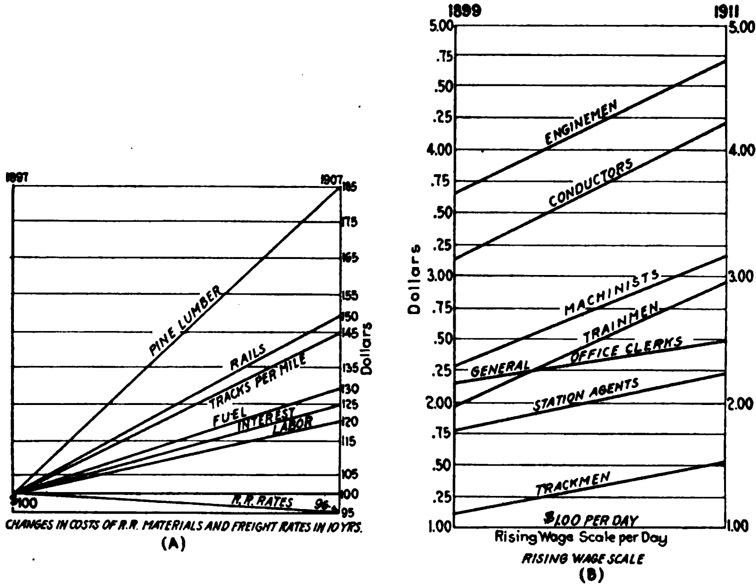


FIG. 77.

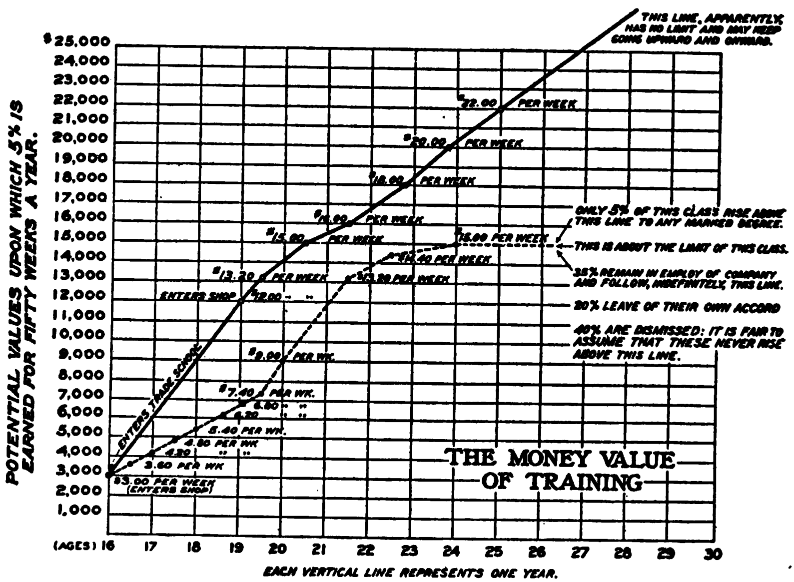


FIG. 78.—Diagram giving curves showing the comparative value of trade school and shop trained boys. Curves plotted from records of two groups of 24 boys each.

plotting to a board designed to show the standing from day to day of operations being performed in the shops in the process of making a finished object from raw material or the hours spent

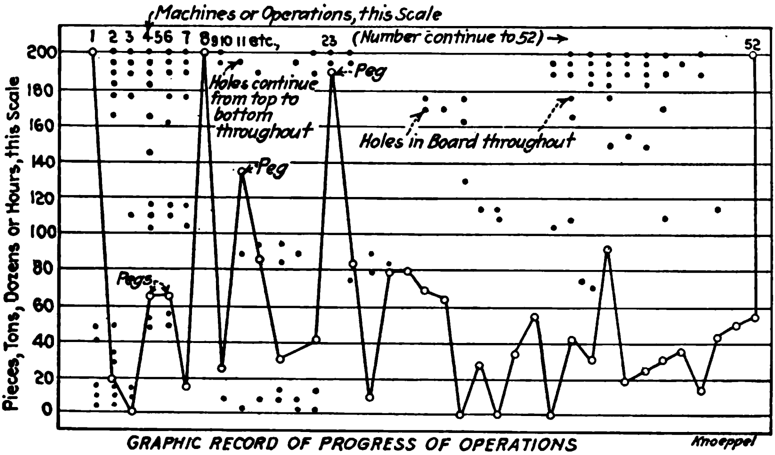


FIG. 79.—Graphic control board.

on such operations. By means of this board the engineer or executive is informed of the progress of work in the shop and can take steps to correct any faults as soon as they appear.

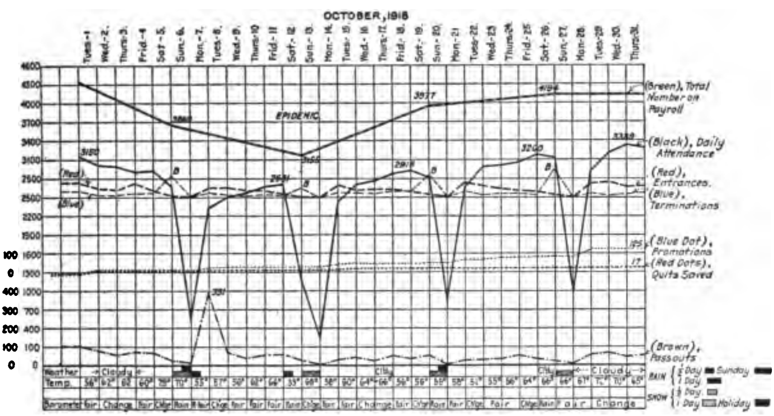


FIG. 80.—Stability chart in use at the works of the Chester Shipbuilding Co.

Figure 80 is a composite diagram dealing with the labor question at one of the shipbuilding yards during October, 1918. Colored ink was used on the original and will be found more effective

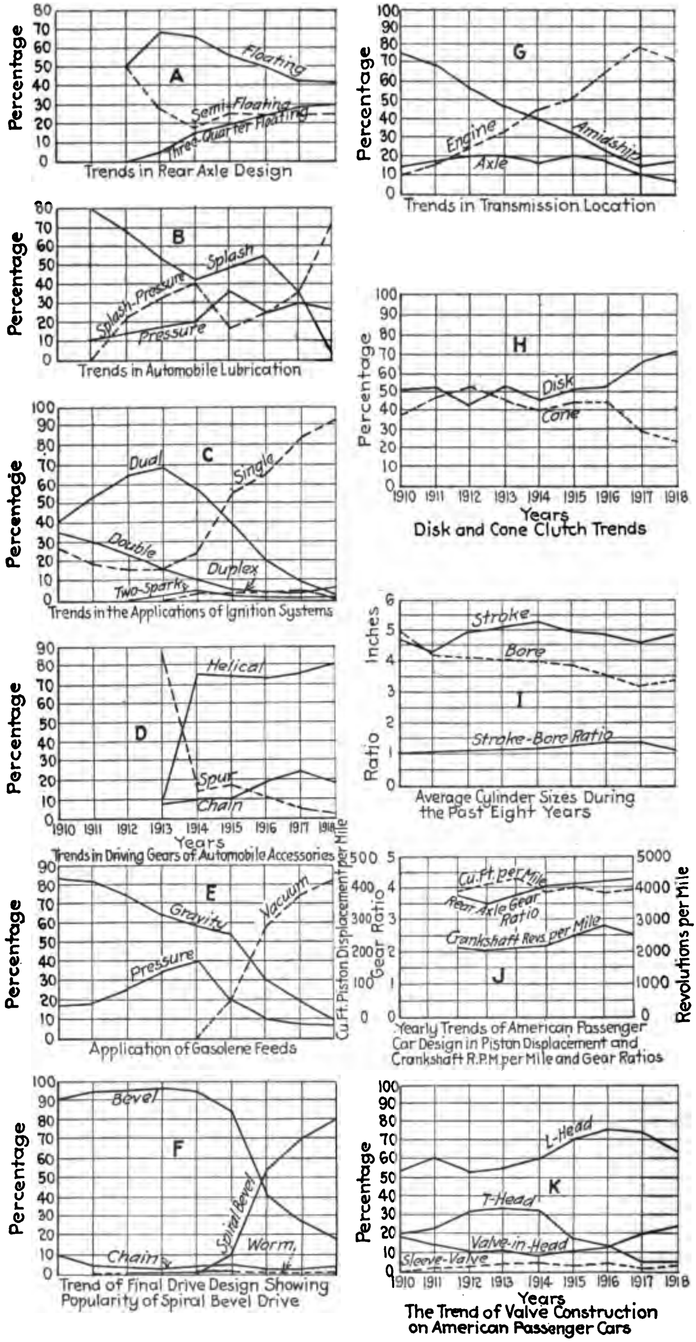


Fig. 81.—Trends of automobile design 1910–1918.

than the variation in the type of line used in the reproduction. The weather report at the bottom acts as a check on a factor which might affect the curves of attendance in the diagram above, such as extreme heat or cold or heavy snow fall.

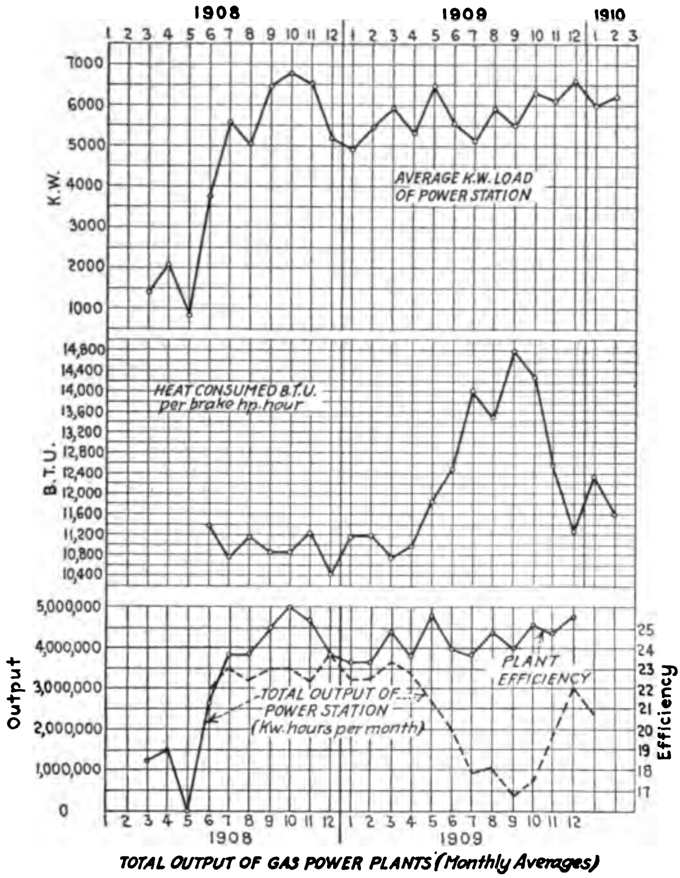


FIG. 82.—Average load, heat consumption, plant efficiency and total output (monthly averages).

The frequency and historical series curves as a rule are based on periods of time, as a term of years, the months of a year, the days of the month, the hours of a day, the minutes in an hour or the seconds in a minute. There may be one curve on a diagram or several to represent fluctuations of one or of several objects or substances. It may be that comparisons are desired or that

the behavior of one thing only is to be studied. All of these objects may be attained graphically in any one of several kinds of diagram as illustrated in Figs. 67 to 80.

The comparison of trends which have no relation to each other makes it useless to bring their graphs on the same diagram, excepting in cases where the observations are based on the same interval of time and over equal periods. For example, all of the 11 diagrams showing trend of automobile design from 1910–1918

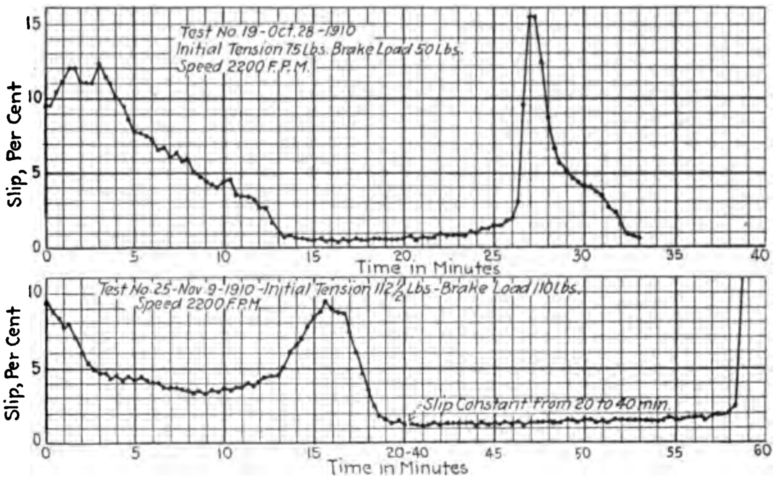


FIG. 83.—Showing various slips of screw propellers.

can be collected into three or less diagrams on the same horizontal base line of years as in Fig. 81, although the curves in each separate block are for different phenomena without relation to each other.

In Fig. 82 the four diagrams illustrating the characteristics of loads, efficiency output and heat consumption of a blast furnace gas power plant can be condensed into three all on a monthly base for 2 years. Figure 83 could just as well have been combined to make one diagram and the curves drawn with different kinds of lines without any detriment to the graphical representation. The base in this case is divided into minute intervals and the observations are clearly indicated by black circles, which makes a clear, readable diagram.

Figure 84 illustrates the use of graphics to represent the comparative and actual number of accidents occurring in the

different departments of a mill for each month during a period of 3 years. A diagram of percentages would be of advantage here to indicate the degree of risk or carelessness in each department and point out where the most attention should be paid to safety appliances.

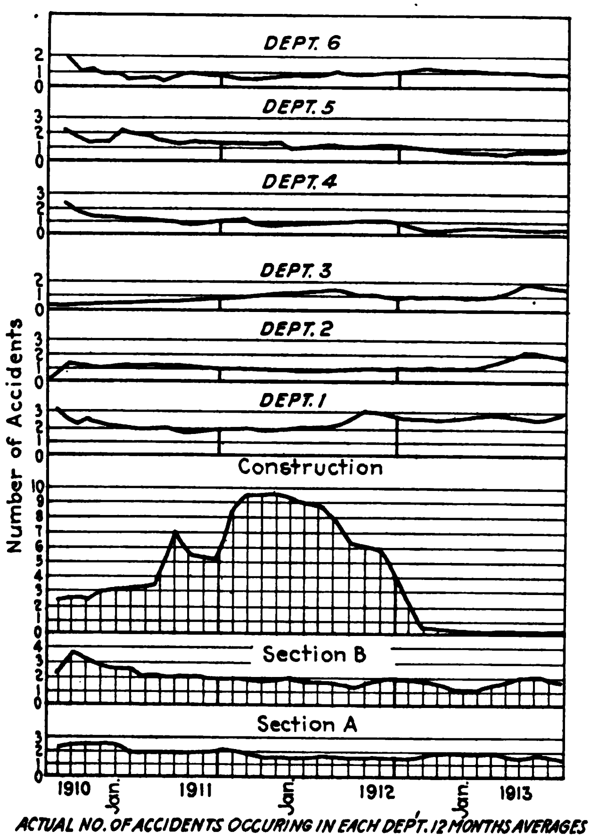


FIG. 84.

Figure 85 is a composite diagram of the operation results of a power plant over a 3-year period by monthly intervals. The data is well arranged so that the influence of some factors on others can be easily seen. All of the data given here can be plotted on yearly record cards, filed in 4 by 6 or 4 by 12 filing cases and transferred to continuous record cards from time to time.

The comparison of occurrences in order to determine if there is any relation between them is shown in Fig. 86. Here we have two cumulative production curves compared with prices of a

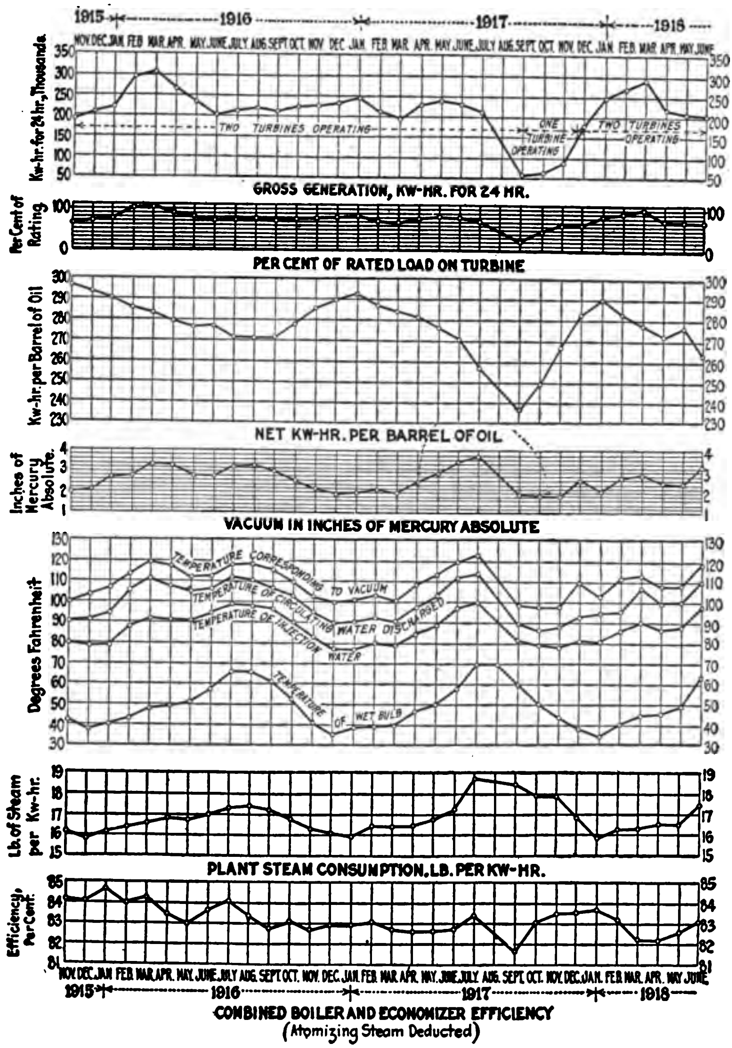


Fig. 85.—Operating characteristics of a power plant.

substance which plays an important part in the maintenance of the objects produced. It is evident there is no relation between these two nor can they be compared to any advantage.

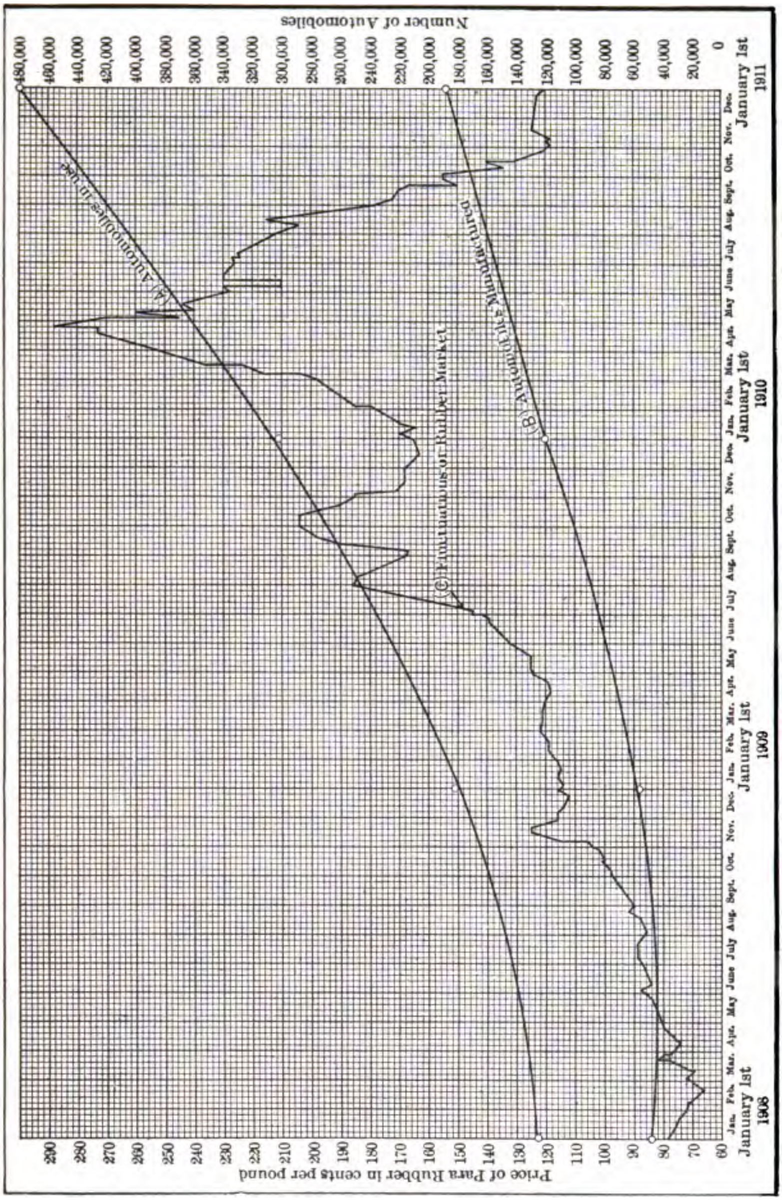


FIG. 86.—Charted to give at a glance the rubber market for three years and the automobile output and sale for the same time.

Cumulative curves are often used to enable a schedule production graph to be established and comparisons to be made between the schedule and actual production.

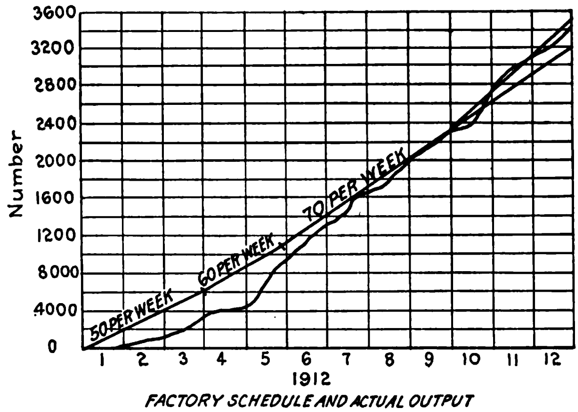


FIG. 87.

Such a diagram is shown in Fig. 87 and illustrates by the solid straight line the expected or planned production and what actually was produced as per the broken line. This type of curve, a diagram and the table from which the diagram was constructed are shown in Fig. 88 applied to a case where the

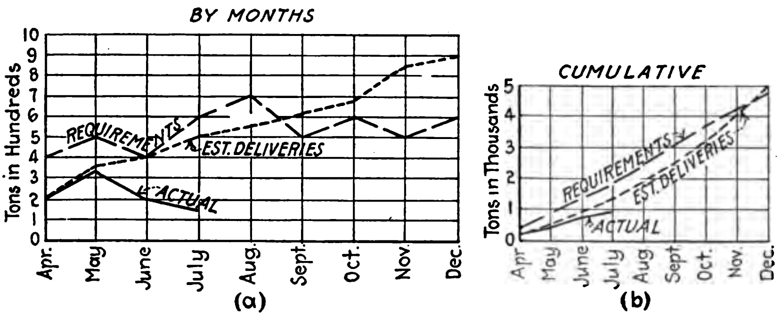


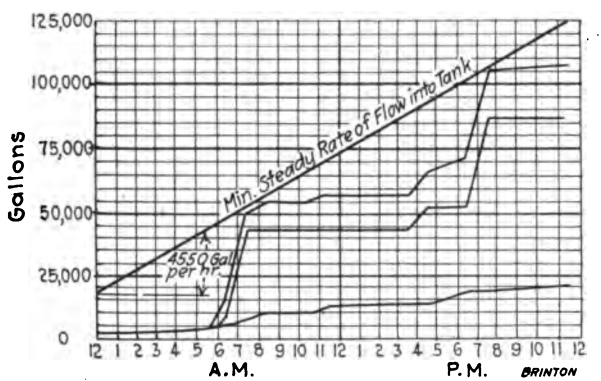
FIG. 88.

requirements called for one rate. Production was planned at a certain rate, but the actual rate fell far below either of the others. Two diagrams were constructed, one for monthly deliveries and another for cumulative deliveries.

Requirements, Estimated and Actual Deliveries
Manufactured Track

1918		Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
For	Req'd.	400	500	400	600	700	500	600	500	600
the	Est.	200	350	400	500	550	625	675	850	900
month	Del.	200	330	200	150					
Cumul. through the month	Req'd.	400	900	1,300	1,900	2,600	3,100	3,700	4,200	4,800
	Est.	200	550	950	1,400	1,950	2,575	3,250	4,100	5,000
	Del.	200	550	750	900					

An application of the cumulative graph is shown in an interesting case where the amount of water in a tank must not fall below the maximum requirements of several tug boats and a locomotive (Fig. 89.) The maximum amount of water drawn at any



Cumulative curves to determine minimum s ze of tank and minimum steady flow of water required For a group of locomotives and tug boats taking boiler feed water from same source of supply.

Fig. 89.

period falls just below the line denoting the minimum steady rate of supply, which is a cumulative line.

The total production estimated for United States rifles which was divided among three plants is shown in Fig. 90. The quantity each plant was to supply is indicated by a cumu-

lative curve for each plant and the total of all three plants is summed up by the total production schedule curve.

The progress chart of one of the plants concerned with rifle production as scheduled from Fig. 90 is shown in Fig. 90*A*. Both weekly and monthly records are shown on the same chart, the latter being cumulative. Dates are given along the base line, the weekly assembly scale at the right and the total assembly

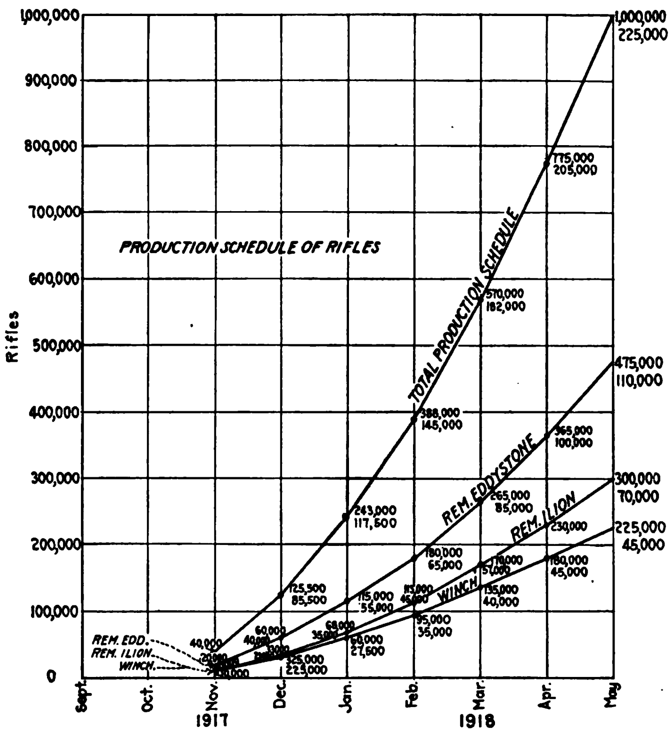


FIG. 90.—Production schedule of rifles.

scale at the left. A chart showing the progress of manufacture of component parts in a plant is often of the type of Fig. 90*B*. The three charts, Fig. 90, 90*A* and 90*B*, complete a set showing the progress of manufacture in a series of plants making the same product, all under one control. The efficiency of each department or plant can thus be compared to each of the others and remedies suggested for increasing the efficiency of the inefficient ones.

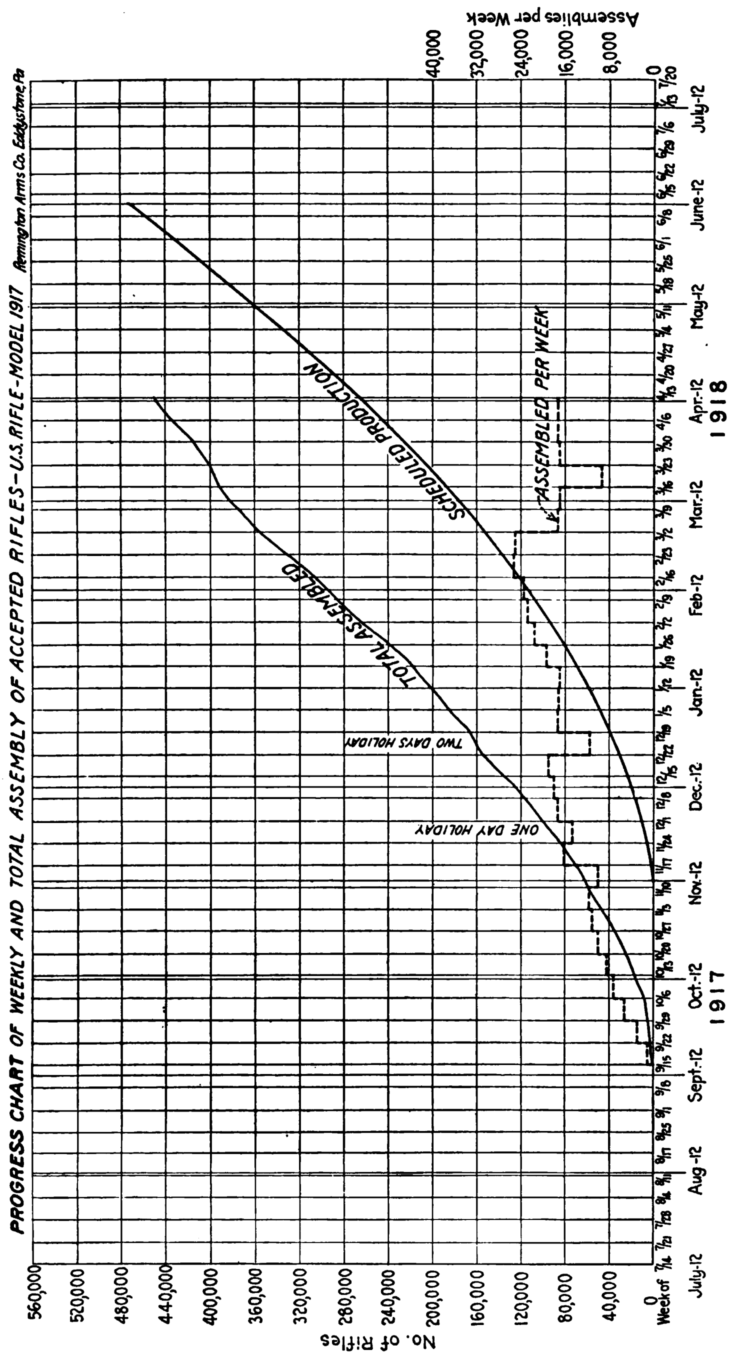
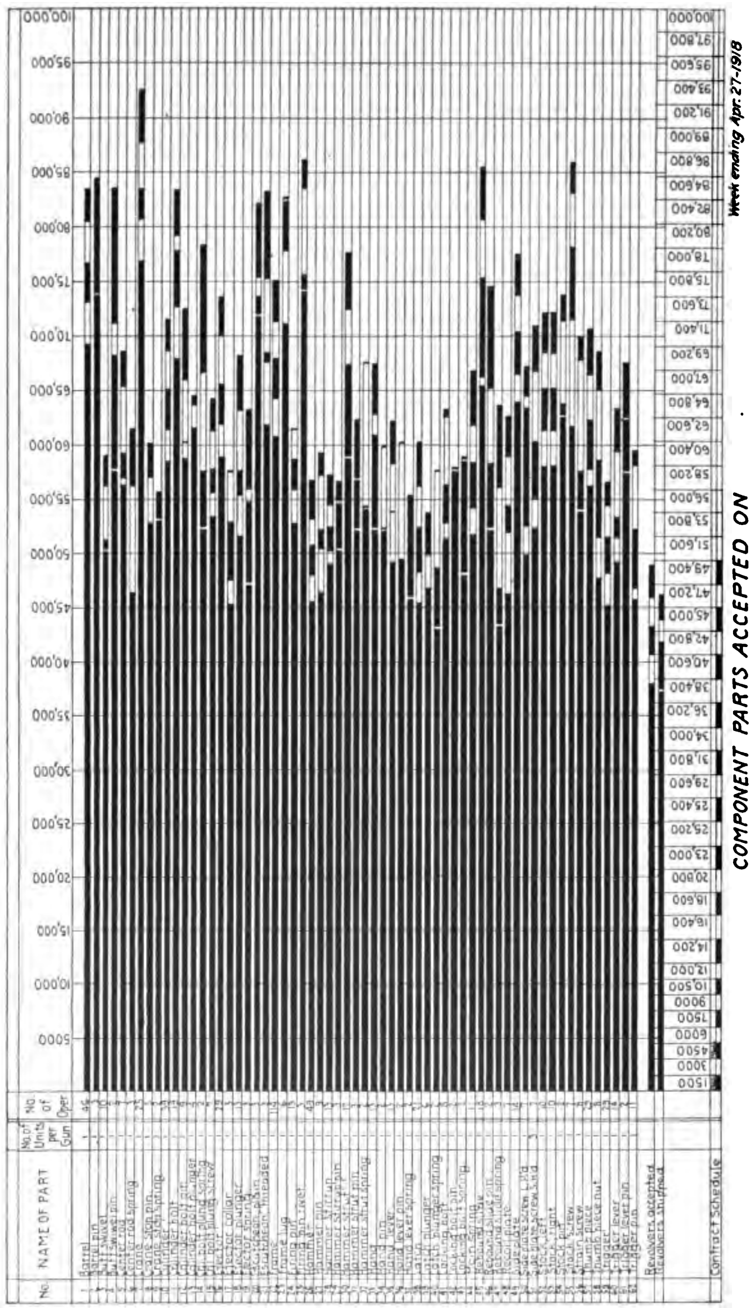

PROGRESS CHART OF WEEKLY AND TOTAL ASSEMBLY OF ACCEPTED RIFLES-U.S. RIFLE-MODEL 1917
Remington Arms Co. Eddystone, Pa
No. of Rifles
Assemblies per Week
SCHEDULED PRODUCTION
TOTAL ASSEMBLED
ASSEMBLED PER WEEK
TWO DAYS HOLIDAY
ONE DAY HOLIDAY
1917
1918
July-12
Aug-12
Sept.-12
Oct.-12
Nov.-12
Dec.-12
Jan.-12
Feb-12
Mar.-12
Apr.-12
May-12
June-12
July-12
Week of

FIG. 90A.



COMPONENT PARTS ACCEPTED ON SMITH & WESSON REVOLVER CAL. 45 MODEL 1917

FIG. 90B.

A diagram like Fig. 91 enables total costs of manufacturing to be compared with sales income and gives at a glance the point of division between profit and loss. Fixed charges, labor and

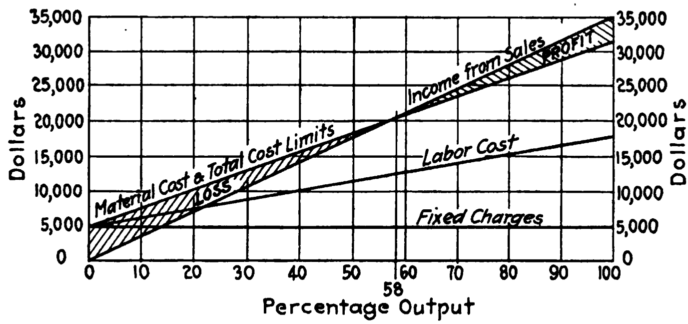


FIG. 91.

materials when added give a cost line. The income from sales increases proportionally to the quantity sold. Anything over 58 per cent output means profit. This shows how a shop laid

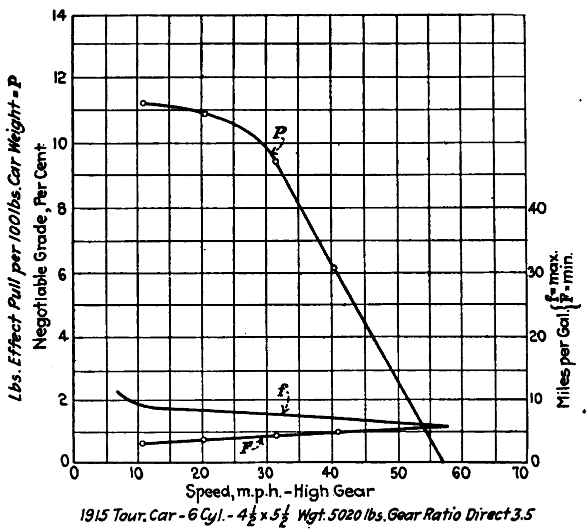


FIG. 92.—Relations of speed, power and gasoline consumption of automobiles.

out on a certain production basis of 100 per cent fails to make a profit when the production falls off to a certain amount depending on the relation of labor, material and overhead costs.

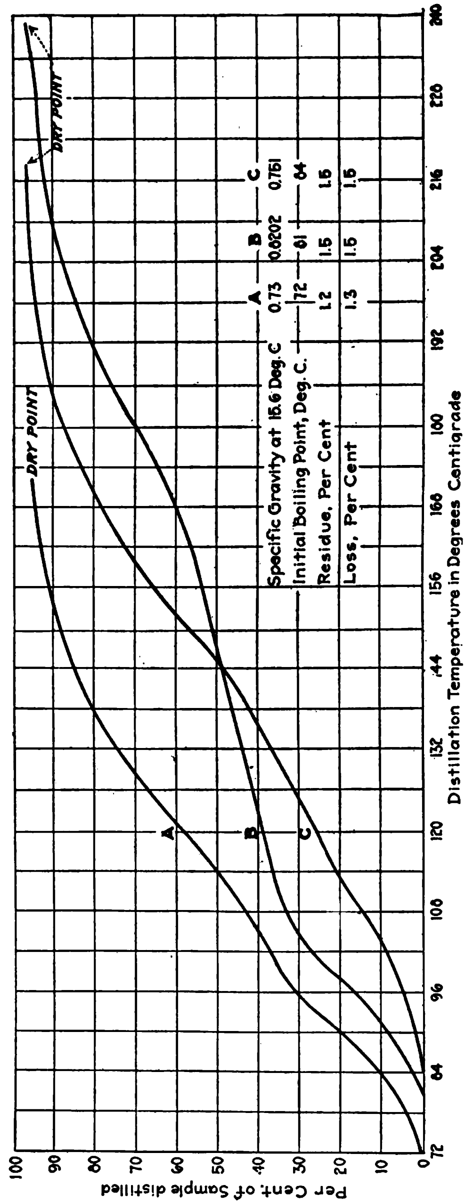


Fig. 93.—Distillation curves of different grades of Liberty fuel.

We now come to a class of diagrams which are not laid off on a time basis but on some other data such as speed, revolutions per minute, per cent, horsepower, diameter, temperature, etc. Closely related to this variable is the variable dependent on the independent variable. For example, consider Fig. 92 which shows

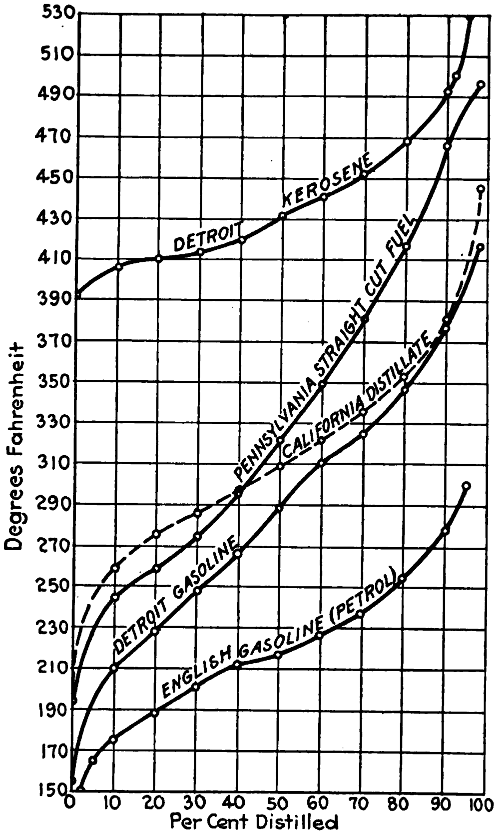


FIG. 93A.—Comparative distillation curves.

the relation between the speed in miles per hour of an automobile and the drawbar pull, also the relation of speed to gasolene consumption. The three curves show this relation, that the faster we go the less power is left for ascending grades and the fewer miles we can go on a gallon of gasolene. In Fig. 93 and 93*A* we have the relation between temperature and amount of gasolene distilled for various kinds of gasolene, shown in a simple

graphical way easy for the average reader to comprehend. In Fig. 93(*A*) is drawn with a horizontal scale of percentages which produces a high, narrow diagram, while 93(*B*) uses temperatures on the horizontal scale which seems more logical and gives a better balanced diagram, *viz.*, long on the horizontal and narrow from bottom to top.

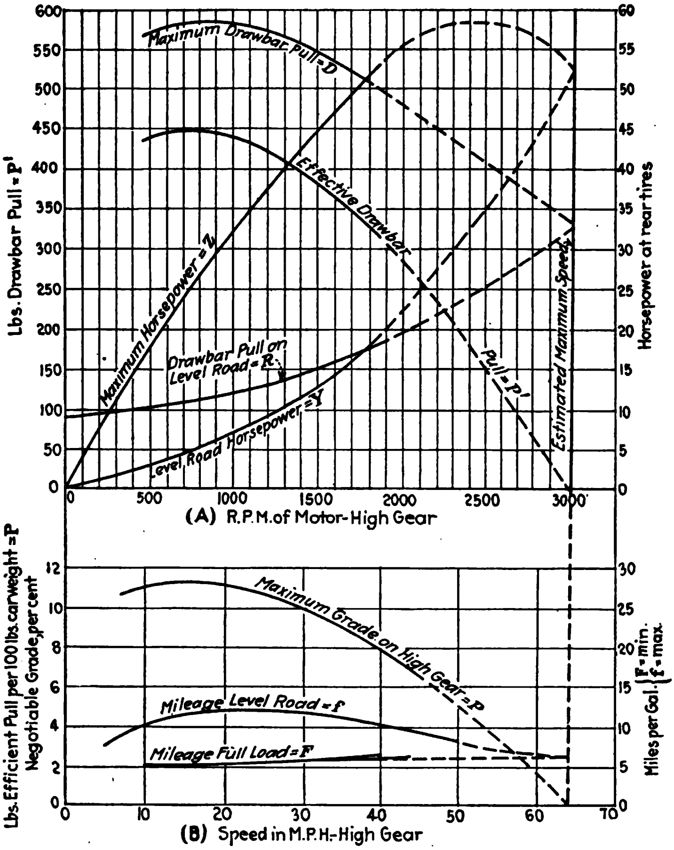


Fig. 94.—Automobile characteristics.

Figure 94(*A*) and (*B*) are shown the relations existing between revolutions per minute, drawbar pull and horsepower and between speed, grade ascendable and miles per gallon of gasolene.

In Fig. 95 are shown curves of tests made on an automobile motor to determine certain effects of back pressure, etc., when

the motor was run at assumed revolutions per minute. These are plotted from the experimental determinations given in Table III. The scales at the sides are of different values depending on the

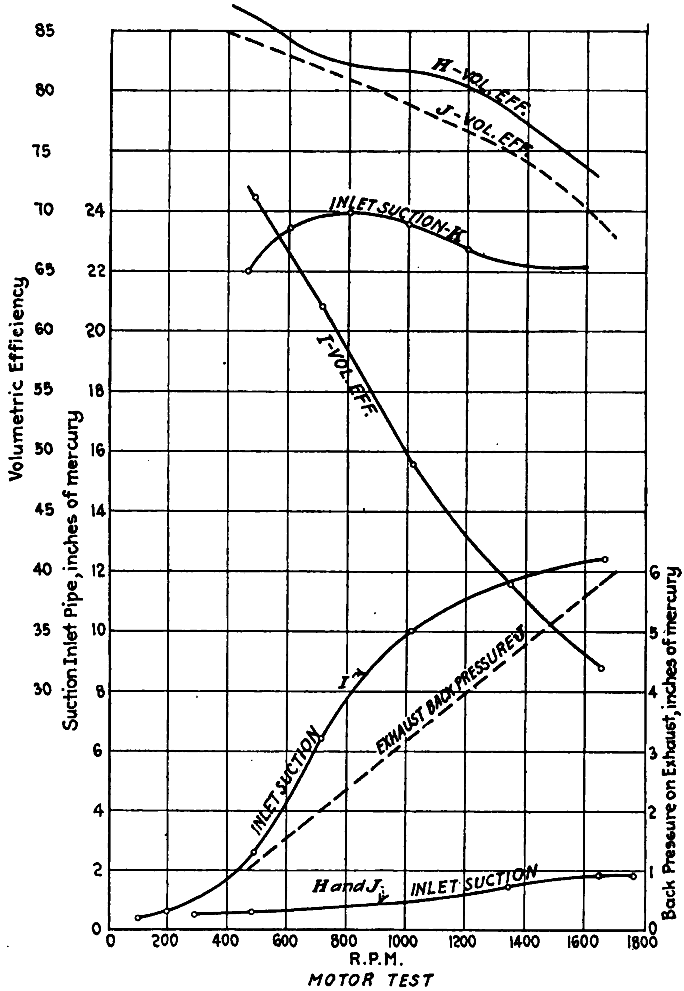


FIG. 95.

magnitude of the observations. This change of scale locates the curves in such a way as to prevent them from interfering with each other and making them difficult to read.

TABLE III TO ACCOMPANY FIG. 95

Curve *H* was Made with Throttle Wide Open; no Muffler

Run.	r.p.m.	Lb. torq. 1 ft. rad.	Volu-metric effic.	Exhaust back press.	suc. inlet	
38	113	19.1			0.5	
39	191	20.5			0.5	
40	292	22.5	0.90		0.5	
41	478	21.4	0.87		0.6	
42	691	27.0	0.83		0.7	(*H*)
43	1,016	34.5	0.82		0.9	
44	1,357	43.3	0.78		1.5	
45	1,641	51.9	0.73		1.7	
46	1,760	55.5	0.70		1.9	
ONE-THIRD THROTTLE; WITHOUT MUFFLER						
47	108				0.7	
48	191				1.1	
49	289				2.0	(*I*)
50	482		0.71		3.1	
51	703		0. 2		6.9	
52	1,015		0.49		10.2	
53	1,344		0.39		12.3	
54	1,660		0.32		12.9	
THROTTLE WIDE; WITH MUFFLER						
55	468	24.0	0.85	1.1	0.6	
56	701	30.9	0.82	2.0	0.7	(J)
57	1,020	40.3	0.79	3.3	0.9	
58	1,344	49.8	0.75	4.8	1.3	
59	1,706	64.5	0.68	6.0	1.7	
INLET MANIFOLD SHUT OFF TIGHT; WITHOUT MUFFLER						
60	469				22.1	
61	605				23.4	(K)
62	1,015				23.8	
63	1,355				22.2	
64	1,626				22.2	
					Inlet suc. inches merc.	

Figure 96 shows the characteristic curves of an automobile motor. In this case the vertical scale is revolutions per minute and there are three horizontal scales, one for horsepower, one for pounds of gasolene and one for torque. The proportions of CO, CO_2 and *O* in the exhaust gas are indicated at various points of the horsepower curve. This is a good example of several curves on the same diagram but without interference.

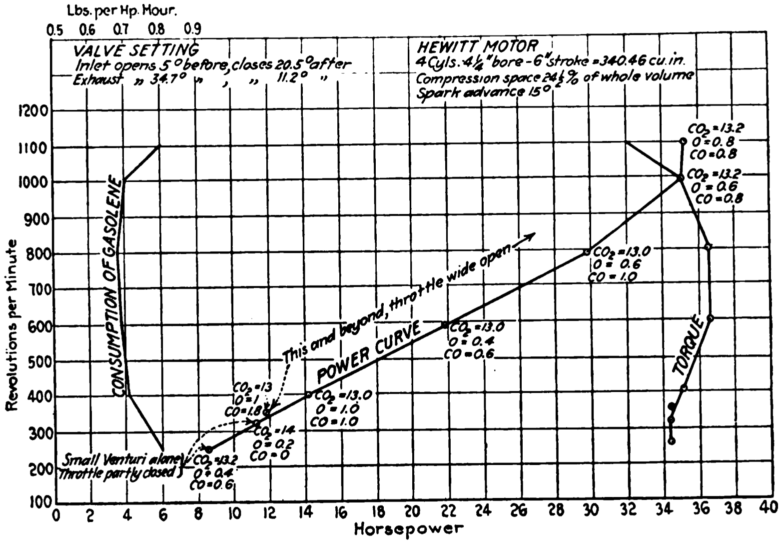
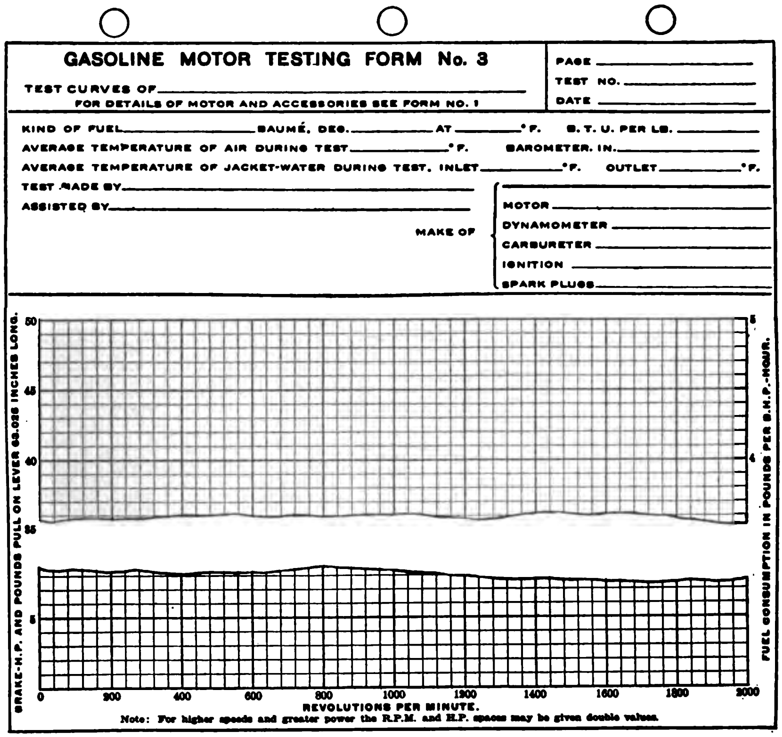


FIG. 96.—Motor characteristic curves.



GASOLINE MOTOR TESTING FORM No. 3

PAGE ______
TEST NO. ______
DATE ______

TEST CURVES OF ______
FOR DETAILS OF MOTOR AND ACCESSORIES SEE FORM NO. 1

KIND OF FUEL ______ BAUMÉ, DEG. ______ AT ______ °F. B. T. U. PER LB. ______
AVERAGE TEMPERATURE OF AIR DURING TEST ______ °F. BAROMETER, IN. ______
AVERAGE TEMPERATURE OF JACKET-WATER DURING TEST, INLET ______ °F. OUTLET ______ °F.
TEST MADE BY ______
ASSISTED BY ______

MAKE OF: ______
MOTOR ______
DYNAMOMETER ______
CARBURETER ______
IGNITION ______
SPARK PLUGS ______

BRAKE-H.P. AND POUNDS PULL ON LEVER 63.025 INCHES LONG.
50 45 40 35 5
FUEL CONSUMPTION IN POUNDS PER B.H.P.-HOUR.
5 4
0 200 400 600 800 1000 1200 1400 1600 1800 2000
REVOLUTIONS PER MINUTE.
Note: For higher speeds and greater power the R.P.M. and H.P. spaces may be given double values.

FIG. 97.—Standard motor testing form, Society of Automotive Engineers.

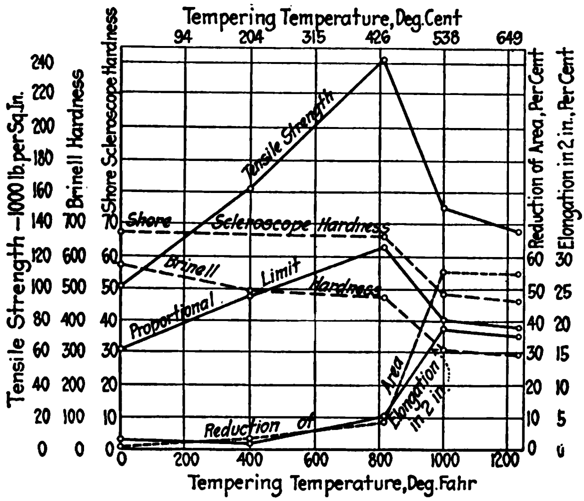


FIG. 98.—Effect of varying temperatures on the physical properties of a high-chromium steel, oil-quenched from 2100 deg. Fahr.

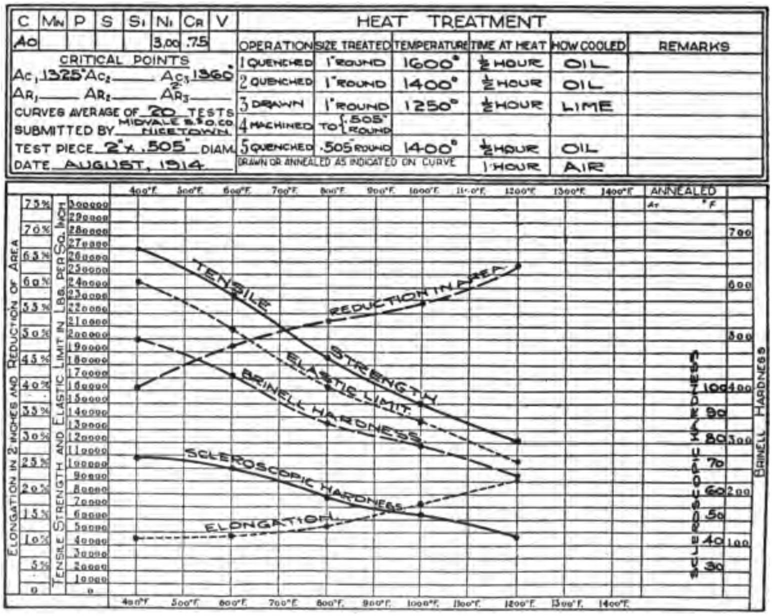


FIG. 99.—Physical properties of a nickel-chromium steel resulting from proper preliminary treatment and varying drawing temperatures.

Diagrams of this type have been brought to a standard form by the Society of Automotive Engineers. This enables graphical comparisons to be made of engines tested in different laboratories

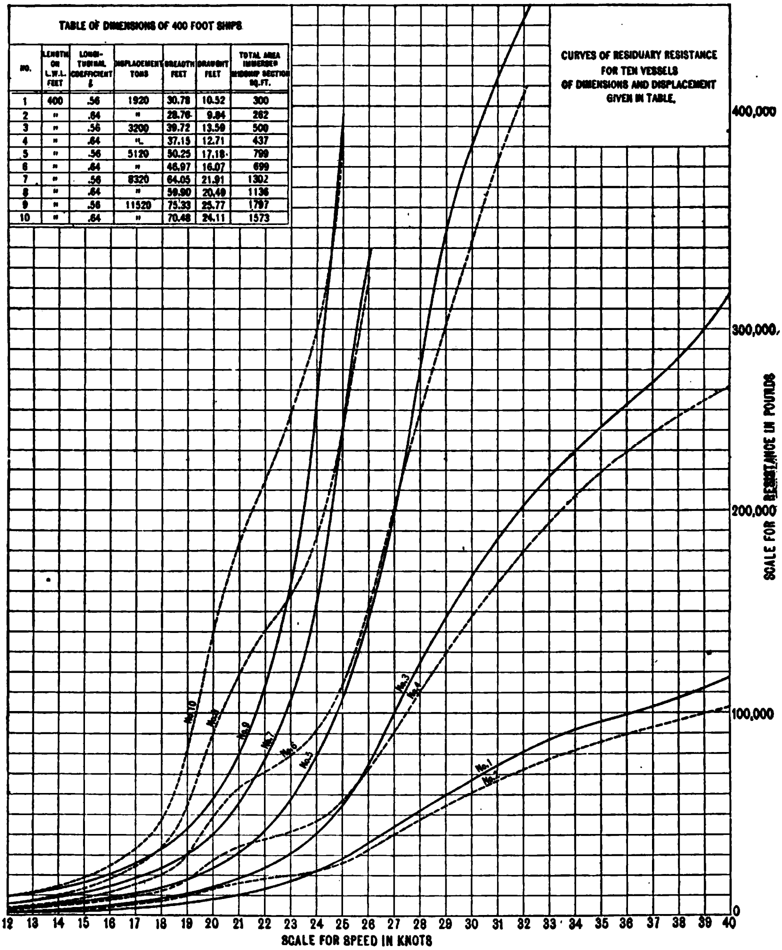


TABLE OF DIMENSIONS OF 400 FOOT SHIPS

No.	Length on L.W.L. Feet	Longitudinal Coefficient δ	Displacement Tons	Breadth Feet	Draught Feet	Total Area Immersed Midship Section Sq. Ft.
1	400	.56	1920	30.78	10.52	300
2	"	.64	"	28.76	9.84	262
3	"	.56	3200	39.72	13.59	500
4	"	.64	"	37.15	12.71	437
5	"	.56	5120	50.25	17.18	799
6	"	.64	"	46.97	16.07	699
7	"	.56	8320	64.05	21.91	1302
8	"	.64	"	59.90	20.49	1136
9	"	.56	11520	75.33	25.77	1797
10	"	.64	"	70.48	24.11	1573

FIG. 100.—Curves of residuary resistance for 10 vessels of dimensions and displacement given in table.

as the test results are presented in the same manner. Figure 97 shows this standard form.

A graphical representation of the behavior of steel is shown in Fig. 98. This diagram gives all the information necessary to

have in order to properly judge how this steel must be treated to obtain certain results. The upper and lower bases are a Centigrade and Fahrenheit temperature scale and are useful as a conversion scale in themselves. There are five vertical scales for the six curves shown. A form for representing the effect of

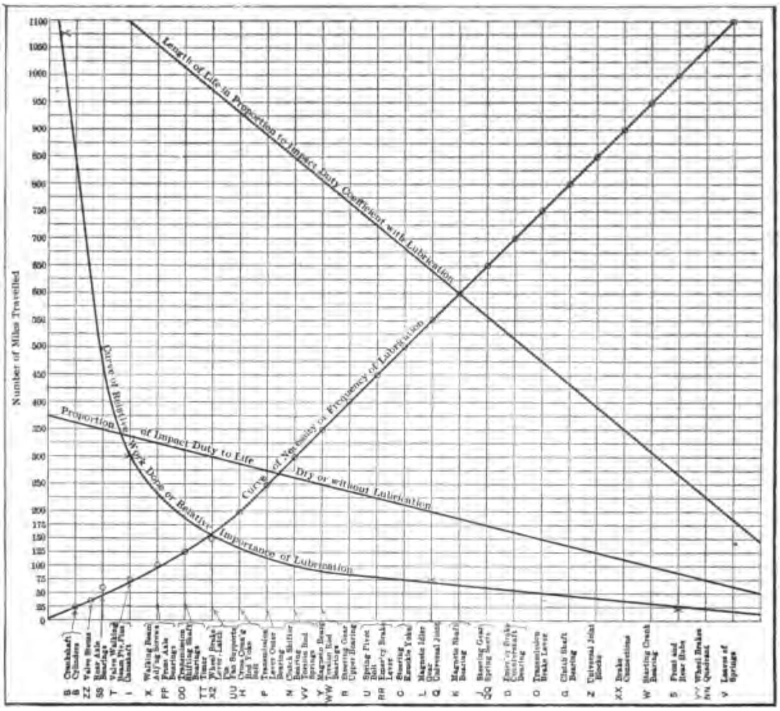


Fig. 101.—Curves which show relation of frequency of lubrication to relative work done and impact-duty coefficient.

various drawing temperatures on the physical properties of steels is shown in Fig. 99. This form is in general use for illustrating test reports as it is clear and gives all the information used in the comparison of steels.

In Fig. 100 are shown comparative resistance curves of 10 vessels run at various speeds which are laid off along the horizontal axis. This shows very plainly the tremendous increase in resistance of most of the models when driven at high speed.

Figure 101 is a type of diagram which is instructive rather than comparative as it shows what parts of an automobile require the

maximum attention to lubrication. The horizontal scale is based on the arrangement of parts in order of importance of lubrication and the vertical scale is according to the number of miles traveled.

Figure 102 shows the variation in chemical analysis of a number of samples of barrel steel used in the Russian military rifle. The limits of the chemical per cent of the various metals are shown by horizontal lines marked maximum and minimum.

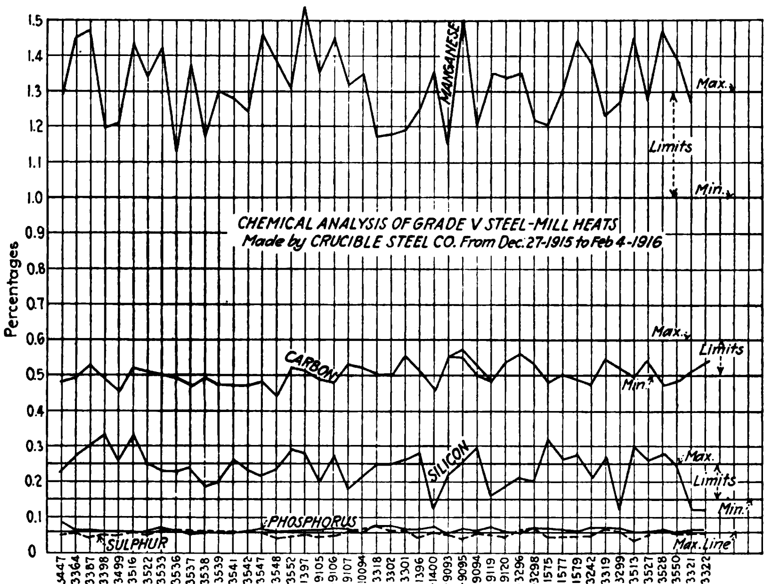


FIG. 102.—Chemical analysis of steel.

This diagram was used to point out in a graphical manner that certain samples of steel did not meet the specifications and that the general trend was in the wrong direction, too high for phosphorus, too low for carbon and too high for manganese and silicon.

In calculations to determine the horsepower of engines it is necessary to know the average pressure of steam or gas on the piston of the engine. This pressure is obtained by connecting the interior of the cylinder with a tracing point so that the pressures in the cylinder will be graphically recorded. The line thus drawn constitutes an *indicator card*. Figure 202, Chapter

IX, is an indicator card from a steam engine cylinder. A card plotted from the pressures in a gasolene engine cylinder is shown in Fig. 103. The dotted line is an enlargement of the lower part of the pressure curve. If this indicator diagram should be drawn on log-log paper we would have Fig. 104 which is interesting chiefly from the standpoint of showing that the expansion

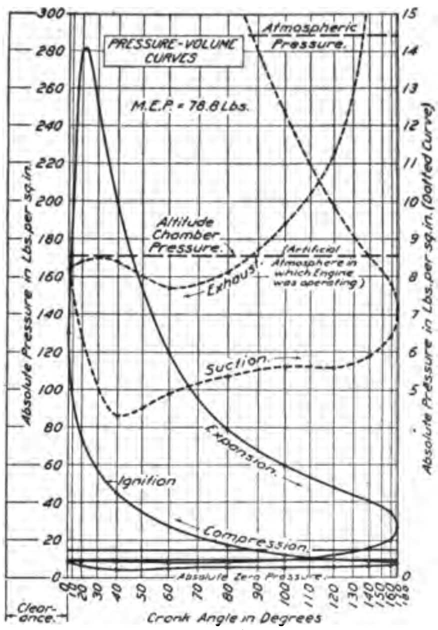


FIG. 103.

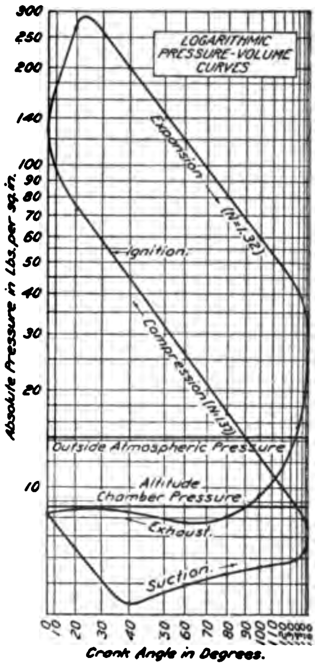


FIG. 104.

FIG. 103.—Specimen indicator diagram in the usual pressure volume scaling. The lower loop is reproduced magnified 20 times, in the dotted curve, to which the scaling in the right hand margin applies.

FIG. 104.—Indicator diagram of Fig. 103 redrawn on logarithmic paper.

and compression curves are exponential and appear as straight lines. Both of these diagrams are plotted on the basis of pressures and volumes. If the data is plotted on the basis of pressure-time scales the diagram will appear as shown in Fig. 105. The abscissa in Figs. 103 and 104 are distances passed over by the piston, while in Fig. 105 they are distances passed over by the crank pin. Ordinates in all cases represent pressures per square inch.

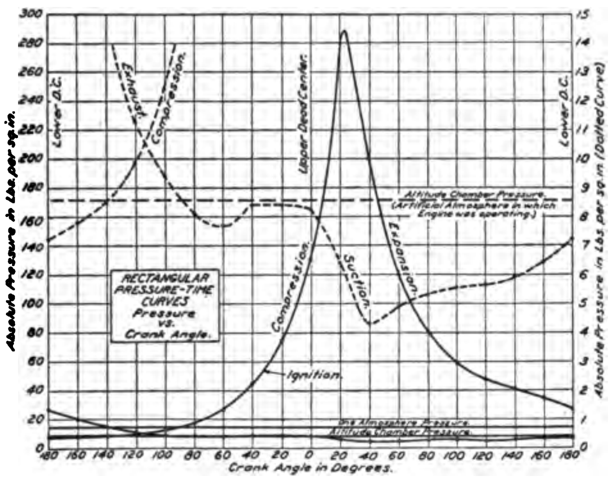


FIG. 105.—Specimen indicator diagram in rectangular coordinates. The diagram is shown by the solid line, the corresponding pressure scale being numbered on the left margin. The portion of the diagram near the zero pressure is reproduced in the dotted curve on a scale magnified 20 times, the scale being noted on the right margin.

POLAR CHARTS

These are used to plot curves by polar coordinates and find an application in plotting diffusion of light emanating from a single source which is taken at the center of the circles or for polar indicator diagrams and other similar records. This type of chart has been used to show the effect of the daylight saving law on the working day. Recording temperature instruments, pressure recorders, water meters, flow meters, etc., make use of polar charts.

The ordinates are either straight or curved depending on the type of tracing point used. The circumference is usually divided on a time basis of 24 hr., the rotation of the chart being obtained from a clock. Samples of records on polar coordinate paper will be found in Chapter IX.

Polar indicator diagrams showing pressures *vs.* crankshaft or camshaft angles are sometimes used in connection with internal-combustion engine investigations. An illustration of this use is shown in Fig. 106. Two scales are used, the larger one enabling the indistinct part of the indicator curve to be plotted more clearly.

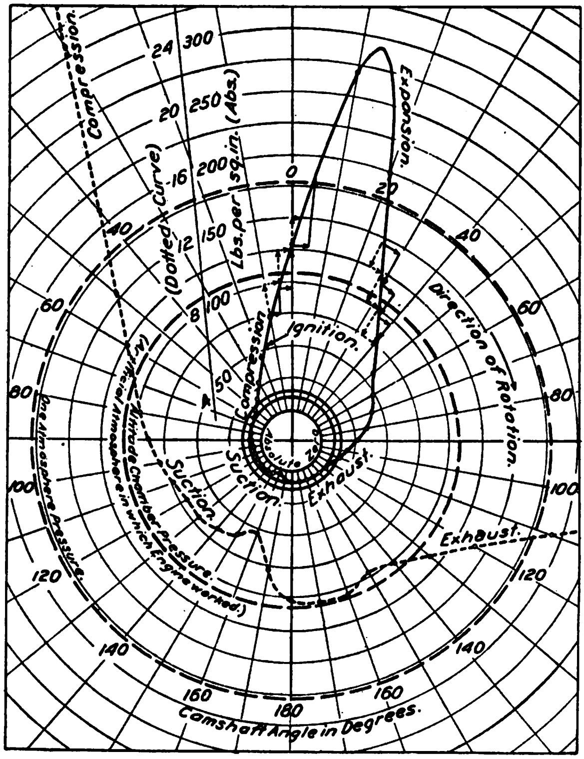


Fig. 106.—Specimen indicator diagram in polar coordinates, pressures *vs*. cam-shaft angle. The diagram is shown by the solid line, to which the right-hand pressure scale applies. That part of the curve near the pole is shown in the dotted curve, to which the $12\frac{1}{2}$ times magnified left-hand scale applies.

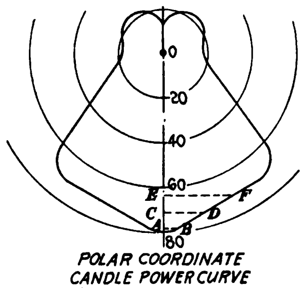


Fig. 107.

Figure 107 is a curve of candlepower plotted on polar coordinate paper. This curve is the common means of expressing the intensity of candlepower of light in various directions from a source. The candlepower is shown by the distance of the curve from the light source. Such a curve gives at a glance a good idea of the characteristics of light distribution from the source. The light flux in various zones is proportional to the length of a perpendicular line drawn from the candlepower curve at the middle of the zone to the vertical axis. *AB*, *CD* and *EF* are such perpendiculars. This is called a Rousseau diagram. Its construction is described in "Illuminating Engineering Practice," published by the McGraw-Hill Book Co.

TRILINEAR DIAGRAMS

Trilinear diagrams are used to show the relation of alloys containing three elements, concrete mixtures containing three substances, or any combination composed of three ingredients. The diagram was first suggested by Prof. Ferét in the Annales des Ponts et Chaussees, 1892, and used for investigations on strength of concrete mixtures.

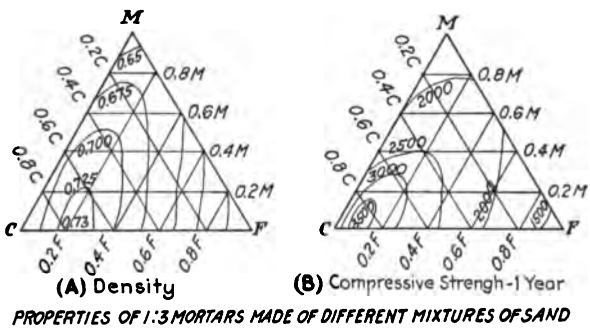


FIG. 108.—Trilinear diagrams of mortars.

In any equilateral triangle the sum of the perpendiculars from any point within to the three sides is equal to the altitude of the triangle. If the altitude represents 100 per cent and a point is taken within the triangle at say one-third the altitude from one side, the per cent. of the other two ingredients can be varied by simply moving along a line parallel to one side and measuring the perpendiculars to the other two. In Fig. 108 are two diagrams showing the effect on mortars by using sand of different

grades of fineness. C = coarse, M = medium, F = fine. The distance of a point in the triangle from the three base lines, represents the proportion of each size used in the mixture. Densities are given in (A) and strengths in (B).

Professor Thurston used this principle in constructing his alloy chart which represented graphically the variation in strength of copper-tin-zinc alloys having different proportions of each. It is also used in dietetics for the proportioning of food rations. The application of this chart is also found in the analysis of coals to show variations in carbon, hydrogen and oxygen. This method of graphical analysis can also be applied to research work on fuels for internal-combustion engines where it is desired to combine those with different British thermal unit values and obtain a constant mixture.

Examples for Chapter IV

1. Construct a diagram to show the relation of dollars and cents to pounds, shillings and pence. (1 pound sterling = $4.87.)
2. Construct a conversion diagram for miles and kilometers.
3. What objections are there to representing quantities by areas or volumes?
4. Plot Fig. 42 to a percentage scale.
5. Using Table I, draw a diagram showing the relation of costs per ton-mile to miles per gallon.
6. Construct in as few diagrams as possible without sacrificing clearness, Fig. 81 *A–J* inclusive.
7. Plot the historigram of automobiles stolen and recovered in Detroit, 1916–18 (*S. A. E. Jour.*, February, 1919).
8. Plot weight of automobiles per cylinder displacement (*Automotive Industries*, Aug. 30, 1917).
9. Plot diagram of comparison of steam and oil engines (*Power*, May 15, 1917).
10. Plot fuel costs for heating and warming (*Power*, Nov. 12, 1918).
11. Make a conversion chart for weight of flat steel and thickness.
12. Plot a curve of electric D. C. motor torque and efficiency (*American Machinist*, Feb. 22, 1917).
13. Plot a curve of hardness tests of brass (*American Machinist*, Mar. 31, 1917).
14. Plot curve of viscosity of oils (*Power*, July 18, 1916).
15. Plot season load curves of central stations (*Power*, July 12, 1917).
16. Plot diagram of test runs of U. S. 110-ft. submarine chaser engines (*S. A. E. Jour.*, May, 1919).
17. Plot price fluctuations of pig-iron and cast-iron pipe (*Engineering and Contracting*, Aug. 29, 1917).
18. Plot production record of soft coal (*Eng. News-Record*, July, 1918),

19. Plot production and consumption of gasolene (*S. A. E. Jour.*, April, 1919).
20. Plot temperature-altitude curves (S. A. E. "Handbook").
21. Plot drawbar pull and horsepower of locomotives (*Railway MechanicalEngineer*, February, 1918).
22. Plot purchase charts (*Industrial Engineering*, March, 1919).
23. Plot withdrawal tests of railroad spikes (*Engineering and Contracting*, Nov. 19, 1919).
24. Plot vol. chart for horizontal cylindrical tanks (*Eng. News-Record*, Vol,. 81, No. 14) (*Power*, Aug. 20, 1918).
25. Plot compensation of engineers (*Trans. Soc. C. E.*, Vol. 81, (1917).
26. Plot surplus dividend fund increase of Fig. 70.
27. Plot line showing excess of married over others as shown by Fig. 73.
28. Combine two diagrams of Fig. 74 whose comparison would be of some advantage as Nos. 6 and 9 or 2 and 7.
29. Plot charts showing wages per month of railroad employees for 1917 and 1921 as follows:

	1917	1921
Carpenters	$ 78.25	$168.95
Boiler makers	118.75	195.11
Watchmen	74.67	154.13
Section men	50.00	112.52
Section foremen	73.75	168.10
Unskilled labor	57.92	118.14

30. Combine the two diagrams in Fig. 55 on one base.
31. Plot data in Table III(H) on the standard form of the S. A. E. in Fig. 97.
32. Plot for 21 knots the resistance of each model using as the other variable the area of immersed midship section of Fig. 100.
33. Plot a diagram of differences from the data given in Fig. 102.

Problems for Graphical Solution

1. A syphon would empty a cistern in 48 min. while a cock would fill it in 36 min. When it is empty both begin to act. How soon will the cistern be filled?
2. A man mixes grain worth 30 cts. per bushel with grain at 80 cts. to make 60 bushels worth 50 cts. per bushel. How much of each kind must he take?
3. A and B shoot at a target. A makes seven out of 12 bulls eyes, B makes nine out of 12. They shoot 32 in all. How many shots did each man fire?
4. A and B are two towns 24 miles apart on a river. A man goes from A to B in 7 hr. by rowing the first half and walking the last half distance. Returning he walks the first half at three-fourths his former rate but the

stream being with him he rows at double his rate in coming and he does the whole return journey in 6 hr. Find his rate of walking and rowing.

5. A and B start together to climb a mountain. A would reach the summit $\frac{1}{2}$ hr. before B, but loses his way, goes a mile and back needlessly during which he goes at twice his former pace and reaches the top 6 min. before B. C starts 20 min. after A and B and walking at the rate of $2\frac{1}{4}$ miles per hour reaches the top 10 min. after B. Find rates of A and B and distance to top of mountain.

6. Take a timetable of a railroad which gives the distance between stations and lay out a train chart for 24 hr.

CHAPTER V

DETERMINATION OF LAWS

The straight line as the representation of an equation finds its most direct and important application in the determination of laws embodying the results of experiments. As an example take the following case: In a test on a crane the following values were found for the effort P required to raise a weight W. Find the law of the crane.

W (lb.)	10	20	30	40	50	60	70	80	90	100
P (lb.)	1	1.63	2.13	2.63	3.25	3.75	4.25	5	55.5	6

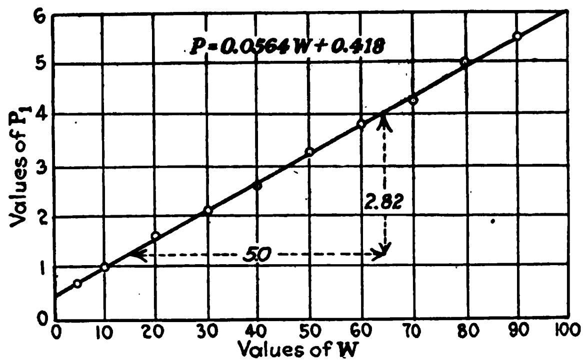


FIG. 109.—Test on a crane.

Figure 109 shows the points plotted on a base line using the values of W as abscissas and the values of P as ordinates. The equation is found to be that of a straight line $P = 0.0564W + 0.418$.

Another example is to find the graph of an equation of the second degree. Equations of this form are $y = 5x^2 + 7x - 9$ or $x = ay^2 + by + c$. If we assume several values for x and calculate the values of y we will be able to plot the graph. For xample take the equation $y = 5x^2 + 7x - 9$. Using values of from $x = -5$ to $x = +4$ and solving for y gives us a curve

which is a form of parabola whose axis is vertical and whose vertex is at the bottom of the curve. This is shown in Fig. 110.

Graphs of equations of higher degree than the second such as $y = x^3$ or $y = x^3 - 8x^2 + 3x + 15$ are plotted as in the following example.

Plot a curve to show the cubes of all numbers from 0 to 6. If x represented the numbers and y the cubes then the equation of the curve is $y = x^3$, Fig. 111. The points all lie on a smooth curve known as a cubic parabola. To read cubes work from the

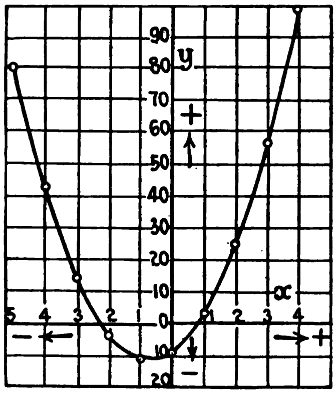


FIG. 110.—Parabola.

number scale up to the curve, then horizontally to the cube scale. For obtaining cube roots the process is reversed.

The horsepower transmitted by a 4-in. belt ¼-in. thick passing around a pulley and running at V ft. per second is given by the equation:

$$H = \frac{V}{1{,}100} - \left(T - \frac{wV^2}{g}\right)$$

T = maximum stress permissible = 350 lb. per square inch
w = mass of 1 ft. length of belt, = 0.4 lb.
g = 32.2

Such a plot is shown in Fig. 112.

Other curves met with most commonly are the conic sections, *viz.*, the ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$ which is the equation when the origin is at the center of the ellipse, as in Fig. 113. As an example plot a curve representing the equation $3x^2 + 5y^2 = 60$. This is the

equation of an ellipse and can be written $\frac{3x^2}{60} + \frac{5y^2}{60} = 1$. Reducing to $\frac{x^2}{20} + \frac{y^2}{12} = 1$ so that $a^2 = 20$ and $b^2 = 12$ from which $a = \pm 4.472$ and $b = \pm 3.464$.

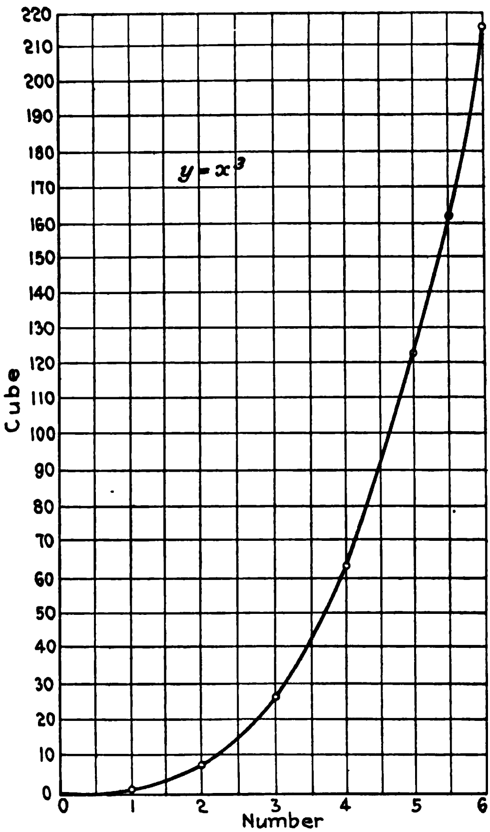


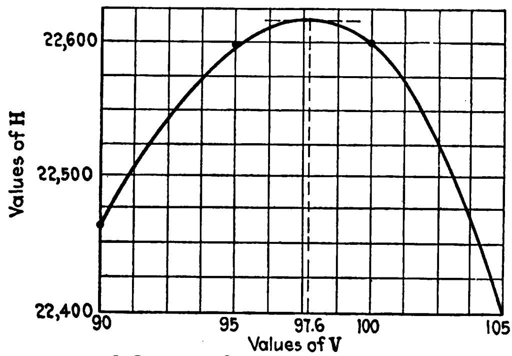
FIG. 111.—Cubic parabola.

A parabola has the equation $y^2 = 4ax$ when the axis is horizontal and the vertex is at the origin. If the axis is vertical the equation is $x^2 = 4ay$. A curve of this kind is shown in Fig. 110.

The Hyperbola.—If the center of the hyperbola is at the origin the equation is of the form $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$.

Example.—Plot the curve representing the equation $2x^2$ –

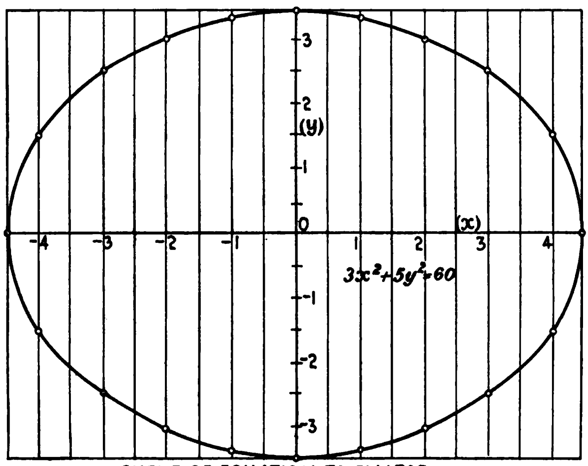
$5y^2 = 48$, Fig. 114. Reduce this to $\frac{x^2}{24} - \frac{y^2}{9.6} = 1$ by dividing by 48. Then $a^2 = 24$, $b^2 = 9.6$ and $a = \pm 4.9$, $b = \pm 3.1$.



CURVE OF HORSEPOWER TRANSMITTED BY BELT

FIG. 112.

Plotting of Difficult Curve Equations.—Type $y = ax^n$. In this case the necessary calculation must be made with the aid of logarithms.



CURVE OF EQUATION TO ELLIPSE

FIG. 113.

As an example of this type of curve, take the expansion curve for gases, $pv^n = c$. p = pressure in pounds per square inch; v = specific volume in cubic feet of 1 lb. and n and c are con-

stants, which vary with the conditions. For air expanding adiabatically $n = 1.41$. For gas in the cylinder of a gas engine $n = 1.37$. For isothermal expansion $n = 1$.

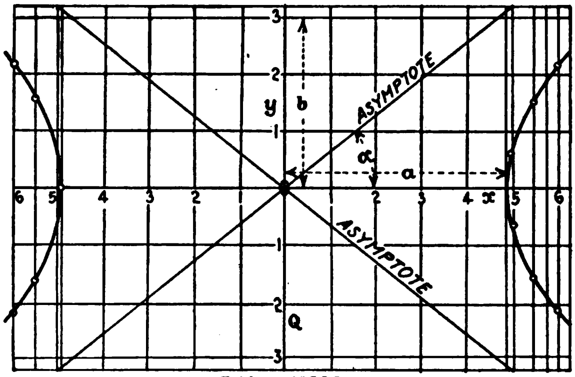


FIG. 114.

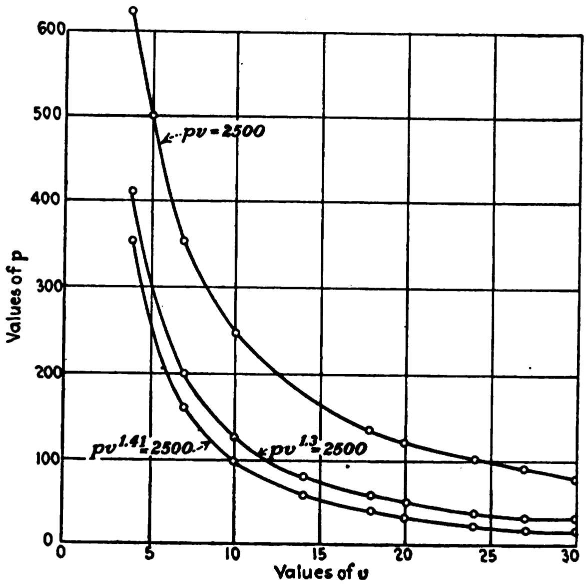


FIG. 115.

Plotting these three curves on one diagram (Fig. 115), using the different values of n enables them to be easily compared.

The greater the value of n the steeper the curve. All these curves are hyperbolas.

The sine curves appearing so often in engineering theory and practice are of the form $y = \sin x$. All sine curves are smooth and of a periodic nature, therefore a study of the simplest case will serve as a basis. To plot $y = \sin x$ select values of x between

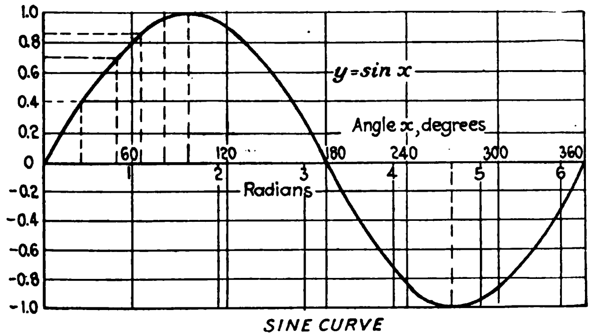


FIG. 116.

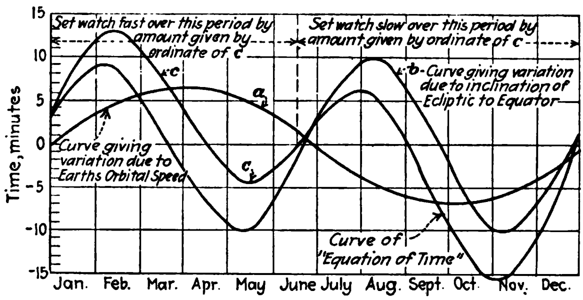
0 and 90°. This will give one-fourth the whole curve, which can then be folded over and inverted. Figure 116 represents the complete plot for values of x from 0 to 360°.

COMPOUND PERIODIC OSCILLATIONS

In engineering practice one often meets with curves which are quite periodic but not of the sine or tangent type. An example of this concerns the equation of time which is the difference between the apparent and the mean time of day. The apparent time is the actual time as recorded on a sun dial while the mean time is calculated by the average over a year. Two causes contribute to the difference between the two times, *viz.*: (*a*) The earth in its journey around the sun moves in an ellipse having an eccentricity $\left(\frac{\text{distance between foci}}{\text{diameter}}\right)$ of $\frac{1}{60}$ and in consequence of the laws of gravity its speed is greater when nearer the sun than when more remote. (*b*) The earth's orbit is inclined to the plane of the equator.

The corrections due to these two causes are found separately and are represented by the respective curves (*a*) and (*b*) in Fig. 117. For (*a*) the period is 1 year; for (*b*) the period is $\frac{1}{2}$

year. These when combined by adding corresponding ordinates, taking account of algebraic signs, give curve (*c*) for which the period is 1 year. By the use of this curve the correction to be added to or subtracted from the observed sun time can be obtained.



CURVE FOR EQUATION OF TIME

FIG. 117.

GRAPHIC SOLUTION OF EQUATIONS

We can apply algebraic rules to the solution of simple or quadratic equations but equations of higher degree or those not entirely algebraic can best be solved by graphs. In some cases no other method is possible. The general plan is to first obtain an approximate idea of the expected result either by rough plotting or calculation and then narrow the range, finally plotting to a large scale the portion of the curve in the neighborhood of the result.

Determination of Laws.—It is often necessary to embody the results of experiments in concise form with the object of simplifying the results for future use. We therefore wish to fit the best law to correlate sets of quantities. The values of the quantities obtained in experiments, except in special cases, do not give straight lines when plotted directly the one against the other. The general scheme then is to first reduce the results to a linear or straight line equation, to plot the straight line and then calculate the values of the constants.

The laws may be of the types (1) $y = a + \frac{x}{b}$, (2) $y = a + bx^2$, (3) $y = ae^{bx}$ (where e 2.718 the base of natural logs) (4) $y = ax^n$, (5) $y = a + bx + cx^2$, and others. The law connecting volts and

amperes of electric arc can be determined from a series of measurements which read as follows:

Volts.......	67	63	59	58	56	53.8	52.2	52.4
Amperes ...	1.95	2.46	3	3.44	3.96	4.99	5.95	7

Plot V against A in the Fig. 118 below. This shows V decreases as A increases or the relation of A and V is of an inverse

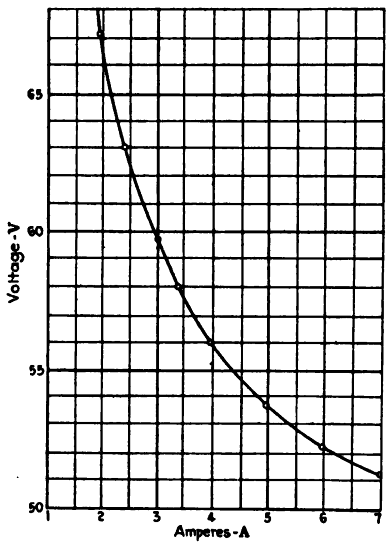


Fig. 118.

character. If we plot $\frac{1}{A}$ against V we have an equation of the form $V = b + \frac{c}{A}$ and the table will be

V....	67	63.7	59.7	58	56	53.8	52.2	51.4
$\frac{1}{A}$....	0.513	0.407	0.333	0.291	0.253	0.2	0.168	0.143

This plot is a straight line as in Fig. 119. Taking two sets of values

$$\left\{ \begin{array}{l} V = 52 \text{ when } \frac{1}{A} = 0.15 \\ V = 64.5 \text{ when } \frac{1}{A} = 0.45 \end{array} \right\}$$

inserting in the formula $V = b + \frac{C}{A}$ gives $C = 41.7$

$$b = 45.75 \text{ whence } V = 45.75 + \frac{41.7}{A}.$$

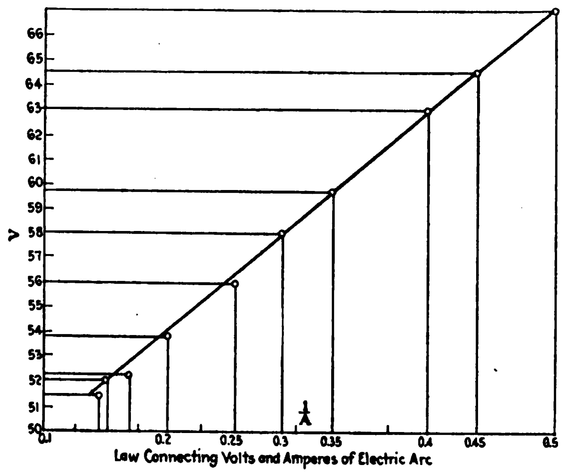


FIG. 119.

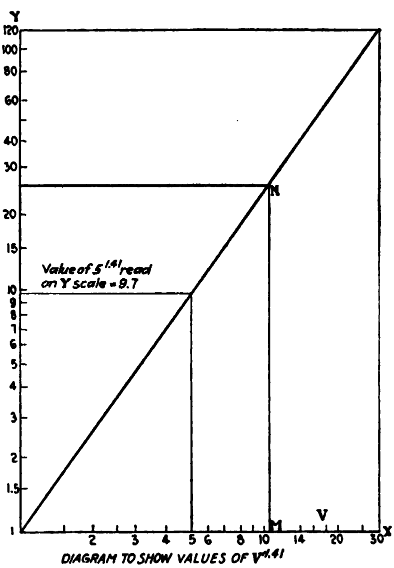


FIG. 120.

PRACTICAL DIAGRAMS

Diagrams may be classified as (*a*) correlation diagrams or graphs, (*b*) ordinary intercept diagrams or (*c*) alignment diagrams.

Correlation diagrams have been treated but adapted for particular circumstances. The modification is in the substitution of a straight line for a curve, as it is easiest to draw. When powers occur this necessitates log plotting. The value of the exponent is thus the slope of the line, hence this method can be used to great advantage when the power is awkward to handle.

As an example in calculating points on an expansion curve values of $V^{1.41}$ had to be found ranging from 1 to 30. To construct a diagram for this, draw axes OX and OY at right angles, and starting from 1 at the point O set off log scales on both axes, the same scale of the slide rule being used throughout. Make $OM = 1$ unit of length and $MN = 1.41$ units of length (actual distance); join ON and produce to cover the given range. Then for $V = 5$, $V^{1.41} = 9.7$. Figure 120 shows this diagram.

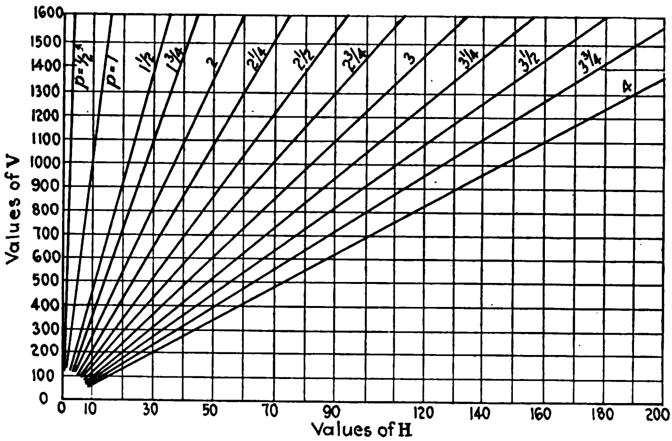


DIAGRAM GIVING HORSEPOWER TRANSMISSION BY C.I. GEARS

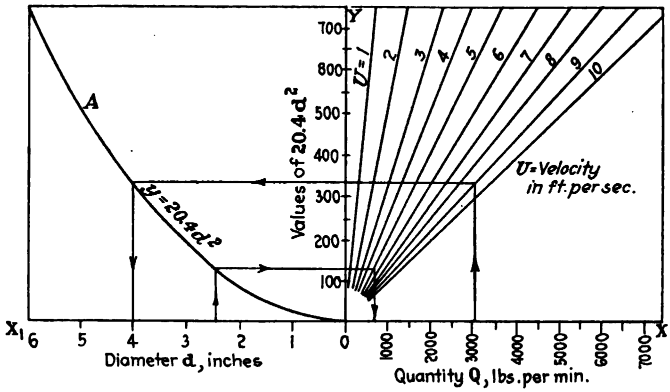
Fig. 121.

ORDINARY INTERCEPT DIAGRAMS

A combination of two or more graphs is often of far more use than the separate graphs since intercepts can then be read directly and from the one diagram.

They may be arranged in various forms, one of them shown in Fig. 121 as an example, being a diagram for horsepower trans-

mitted by spur gears for various pitches and speeds. The pitch varies from ½ to 4 in. and the speed from 100 to 1,500 ft. perm inute. The formula, when all the pressure is taken by one tooth at a time is $H = \frac{P^2V}{110}$. All the calculated values of H produce straight lines which pass through the origin. The diagram appears as follows, in Fig. 121: To use when P and V are given, draw a horizontal line through V to meet the inclined line of given pitch value. From the intersection drop



QUANTITY OF WATER FLOWING THROUGH PIPES

FIG. 122.

a perpendicular line to the H scale which gives the desired answer on H. A diagram to give quantity of water flowing through pipes would appear as in Fig. 122.

Pounds per minute = 60 by 62.4 by area in square feet by velocity in feet per second if

d = inches diam. of pipe.
V = velocity in feet per second
$Q = 20.4\ d^2V$

Another similar diagram is one giving volume of water in cylinderical tanks for various depths and lengths as shown in Fig. 123. Let the depth of water equal h (see E of Fig. 123).

A number of curves should be drawn in the left-hand portion, one for each separate value of the diameter. For diameter = 4 ft. ordinates of the curve would be $(4/2)^2$, *viz.*, four times those of the curve for $d = 2$ as drawn. This crowds the scale so that it is preferable to work from the one curve and to multiply after-

ward remembering that the variation will be as the squares of the diameter.

There is a class of graphical work not yet touched upon which belongs rightfully in a treatise on graphical methods although it is usually found in books on integral calculus, *viz.*, the plotting

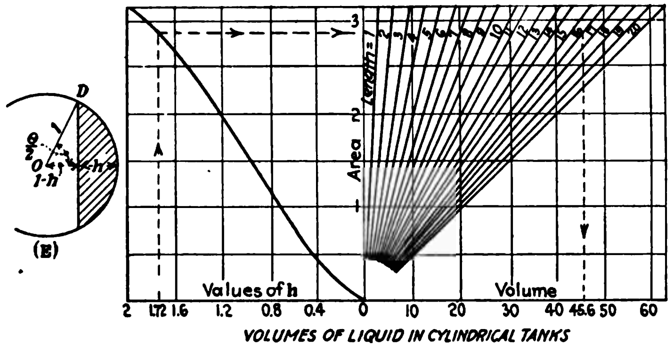


FIG. 123.

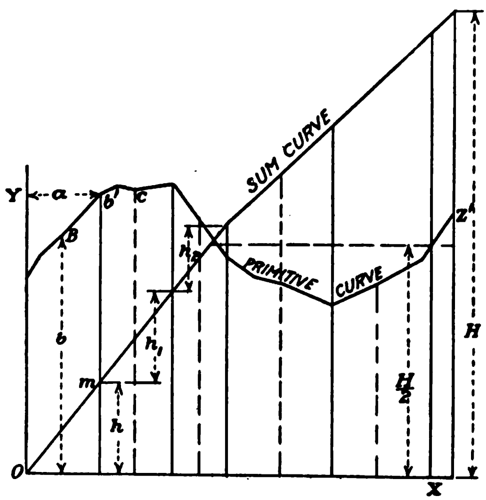


FIG. 124.—Area of irregular figure.

of an integral or sum curve. The application of this is found in problems where it is desired to find the area of a closed figure or the volume of a solid, proceeding by increments. As an example of this, reference is made to the displacement and body curves of a vessel's hull. There are several ways of constructing an integral curve from a given curve. The simplest is to divide

the area under consideration into narrow strips as in Fig. 124. Each strip is approximately a rectangle whose area equals its width a times its average height b. This area is square inches; therefore suppose the area of the first strip is $< >$ X square inches. Lay off this area, to any scale assumed, on the ordinate of the side of the strip farthest from the oy-axis and call it h. Find the area of each of the following strips and lay off the value of each one from the top of the preceding ordinate as h_1, h_2, etc. The last ordinate H will be the sum of all the areas of the strips and will equal the area of the figure between the curve and line ox. If this line is divided into halves and the middle point projected back to the sum curve, an ordinate drawn through this

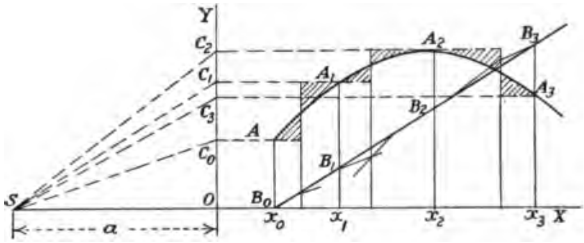


FIG. 125.—Integral of area bounded by curve, ordinates and base line.

point will divide the area of the figure into halves. We can thus divide the figure into any number of equal areas by dividing ordinate H into the required number of parts and projecting the division points back to the sum curve.

Another method of drawing an integral curve is shown in Fig. 125. Divide x_0 to x_3 into n parts and erect ordinates. Through A, A_1, A_2, etc., draw short horizontal lines. Cut the arc AA_1 by a vertical line making the small areas bounded by this vertical, the arc and the short lines through A and A_1 equal. Do this for the succeeding arcs. Choose a point S at a convenient distance to the left of O and join S to C_0, C_1, C_2, etc., the points in which the horizontals cut OY. Then starting at B_0 draw a line parallel to SC_0 until it cuts the first vertical; through this point draw a line parallel to SC_1 until it cuts the second vertical, etc. The points B_0, B_1, B_2, etc., are points on the required integral curve. A smooth curve through these points will be the required curve.

The distance (X_3B_3) equals the area under the whole curve. If (X_3B_3) is measured by the vertical scale and (a) by the horizontal scale the area under the curve will be equal to $(a) \times (X_3B_3)$.

CHAPTER VI

ROUTING AND ORGANIZATION

A type of diagram of the non-mathematical kind is that used for illustrating the route or path of an order from source to destination or the path laid out for keeping track of an article of manufacture as it passes through the shop. It may also be an outline of the processes of manufacture or a flow sheet of all material obtained as a by-product during the reduction of raw material to a final output. As an example of the first type of diagram, Fig. 126 shows how certain forms in the Ordnance Department of the U. S. Army were handled after they were made out. It shows the place of origin and number originally made out, to what offices they were sent and where each one finally arrived and was filed.

In Fig. 127 is shown the flow sheet for one unit of an iron ore washing plant. This shows the outline process from reception of the ore in railroad cars to the final location of ore in bins and washing water used in pounds. A flow sheet of a copper mill is shown more in detail in Fig. 128. This indicates the path of the ore and the processes as regards various levels instead of a bare outline of the operations.

A diagram more elaborate still is shown in Fig. 129. Here the operation of refining crude petroleum and oils is followed from the crude distillate tanks to the tanks storing the final product. Such diagrams as the ones given above serve as a guide to the manufacturing processes of many products but are not in favor with many executives as they only serve to give away to the layman all the information which those in the business know by heart and which it is not desired to spread outside the plant.

Another application of this type of diagram is found in the component and assembly records of manufacturers of machinery or complicated instruments. It aims to show, first, the component parts of the machine, the sub-assemblies into which these parts are collected, and the progress of further assembly up to the final assembly of finished product. Such a diagram is shown

in Fig. 130 which is the assembly routing of the bolt action of model 17 U. S. rifle. These diagrams are used mainly for a first layout of the work of processing and assembling. The routing, inspection and transportation diagrams are worked out from this diagram as a basis.

Organization diagrams or charts, as they are usually named, belong to this class of diagrams. Their function is to arrange in

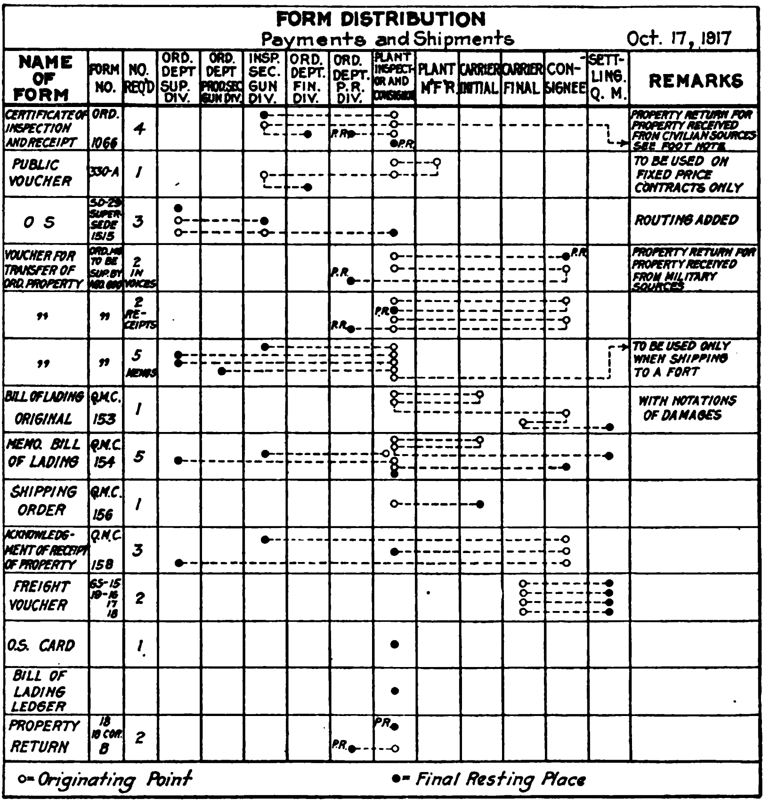
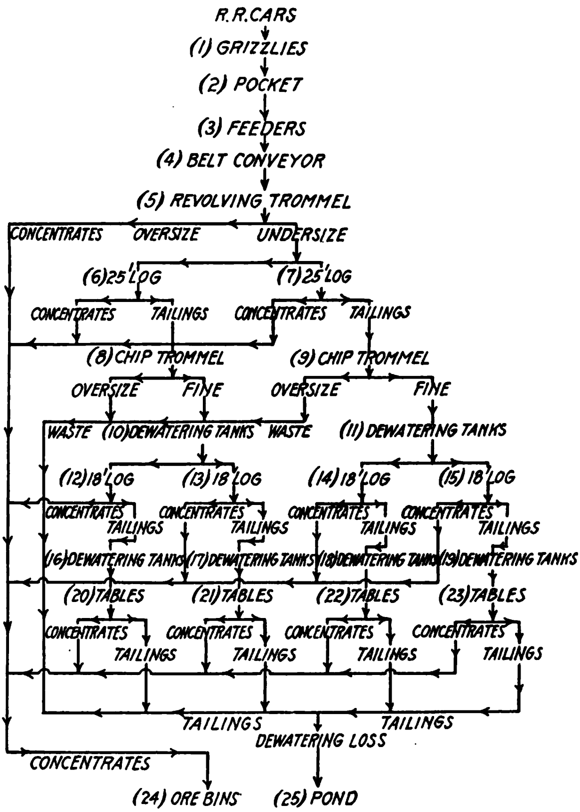


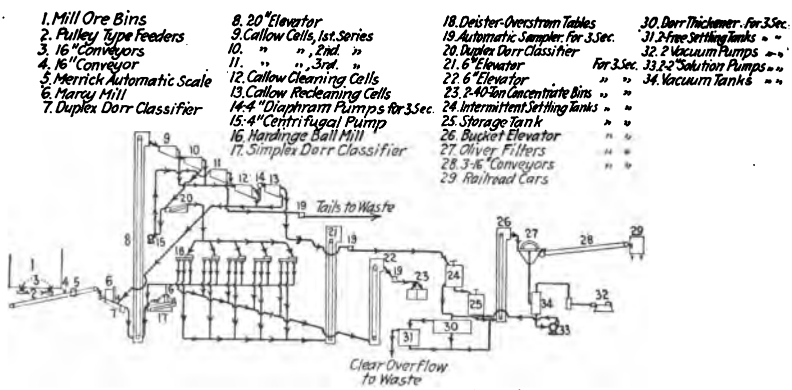
FIG. 126.—Diagram showing method of handling forms in ordnance department, U. S. A., 1917.

a clear form, which can be quickly grasped by the executives, the plan of organization of the working forces of a business or corporation. It shows each employee where he stands in line of responsibility, who is his superior, who must report to him and his relation to the different branches of the organization. These



FLOW SHEET OF ONE UNIT IRON ORE WASHING PLANT

Fig. 127.



FLOW SHEET OF ONE SECTION OF HERCULES COPPER CO'S MILL

Fig. 128.

charts are made out in various ways by using circles or rectangles of different sizes to contain the names of the divisions and sub-divisions of the organization and often the name of the employee

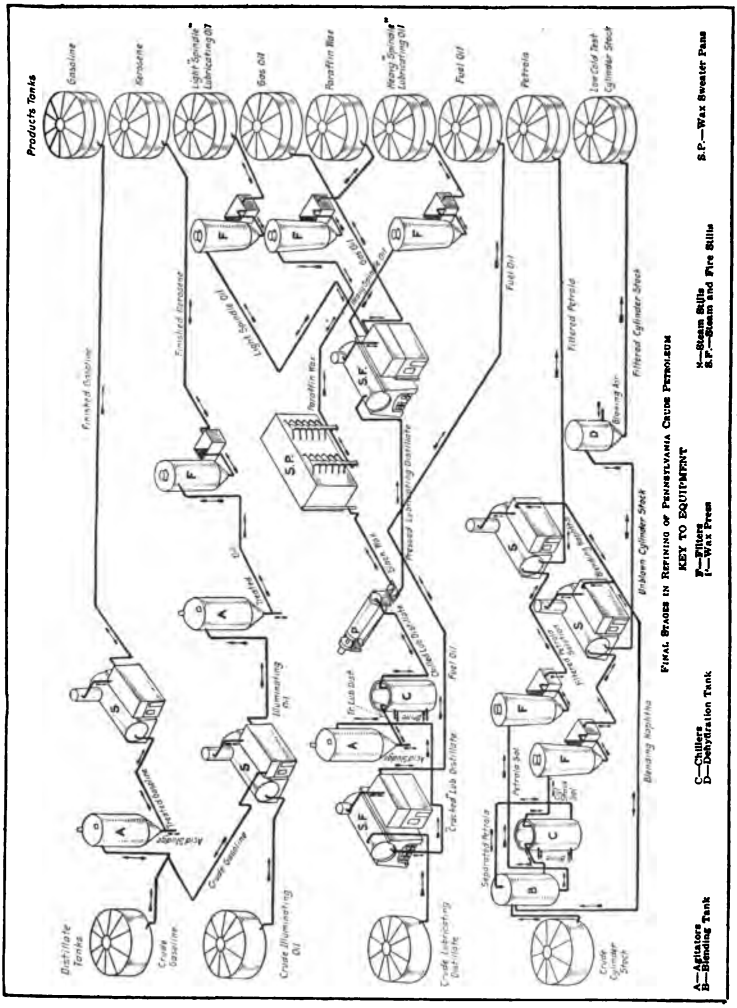


FIG. 129.—Refining processes and routing in refinery for Pennsylvania crude petroleum.

who heads each one. These circles or rectangles are arranged according to the importance of the departments or positions, commencing with the president or board of directors and ending with the foremen or sub-foremen of the shops. The circles or

rectangles are joined by lines in such a way as to convey the relation of one department to another. A sample of organization chart for an automobile manufacturing company is shown in

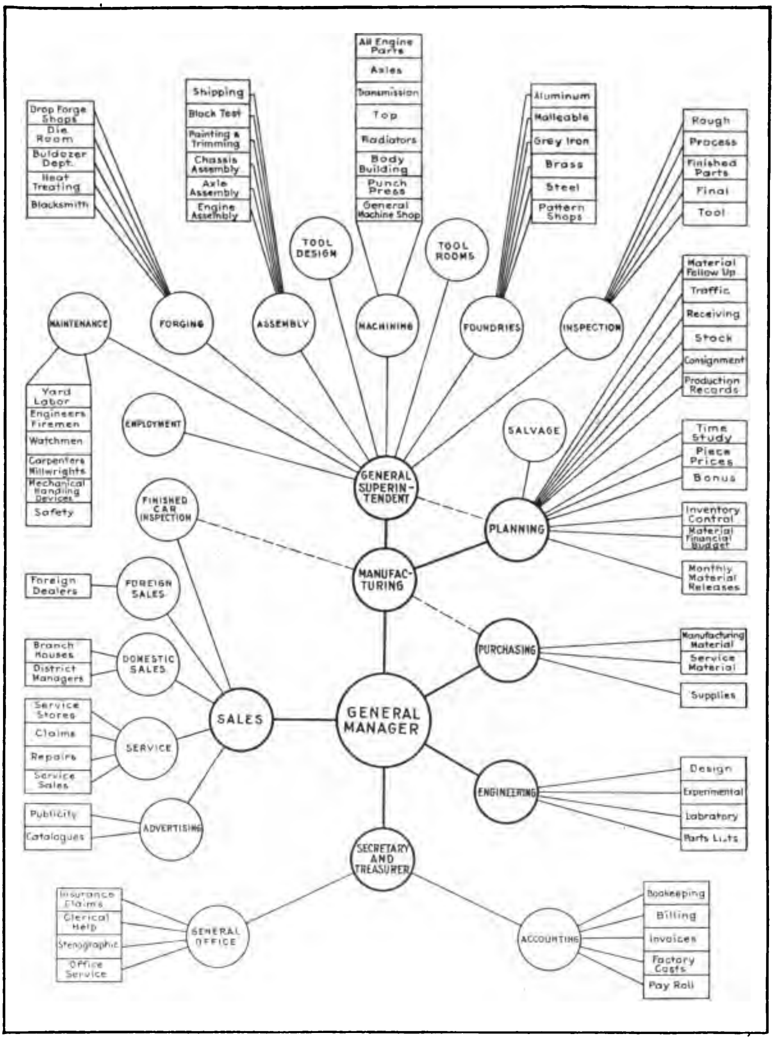


FIG. 131.—Chart showing make-up of various branches and departments of an automobile manufacturing company.

Fig. 131. This does not show necessarily the *best* form of organization as there is a difference of opinion regarding the subordination of certain departments to others. The organization

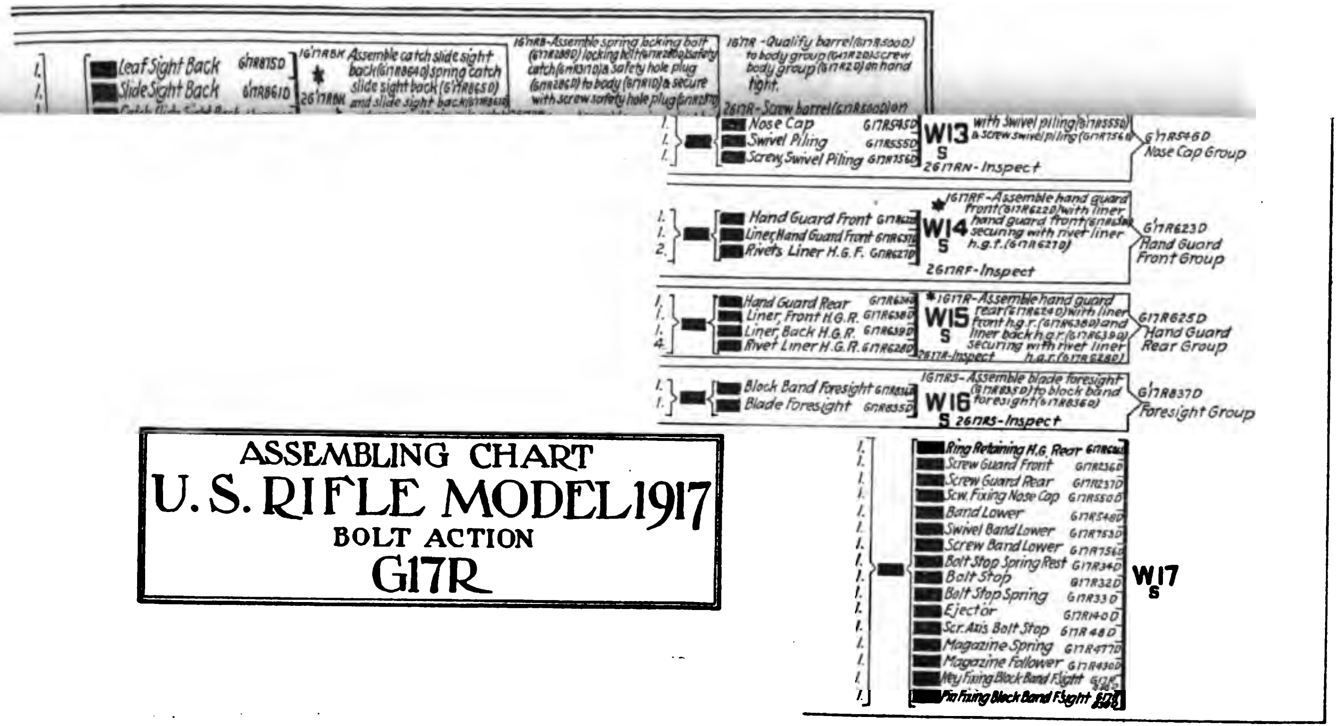

ASSEMBLING CHART
U.S. RIFLE MODEL 1917
BOLT ACTION
G17R
Leaf Sight Back
Slide Sight Back
Nose Cap
Swivel Piling
Screw Swivel Piling
W13
26 17RN - Inspect
Nose Cap Group
Hand Guard Front
Liner Hand Guard Front
Rivets Liner H.G.F.
W14
26 17RF - Inspect
Hand Guard Front Group
Hand Guard Rear
Liner, Front H.G.R.
Liner, Back H.G.R.
Rivet Liner H.G.R.
W15
Hand Guard Rear Group
Block Band Foresight
Blade Foresight
W16
26 17RS - Inspect
Foresight Group
Ring Retaining H.G. Rear
Screw Guard Front
Screw Guard Rear
Scw. Fixing Nose Cap
Band Lower
Swivel Band Lower
Screw Band Lower
Bolt Stop Spring Rest
Bolt Stop
Bolt Stop Spring
Ejector
Scr. Axis Bolt Stop
Magazine Spring
Magazine Follower
Key Fixing Block Band F'sight
Pin Fixing Block Band F'sight
W17

FIG. 130.

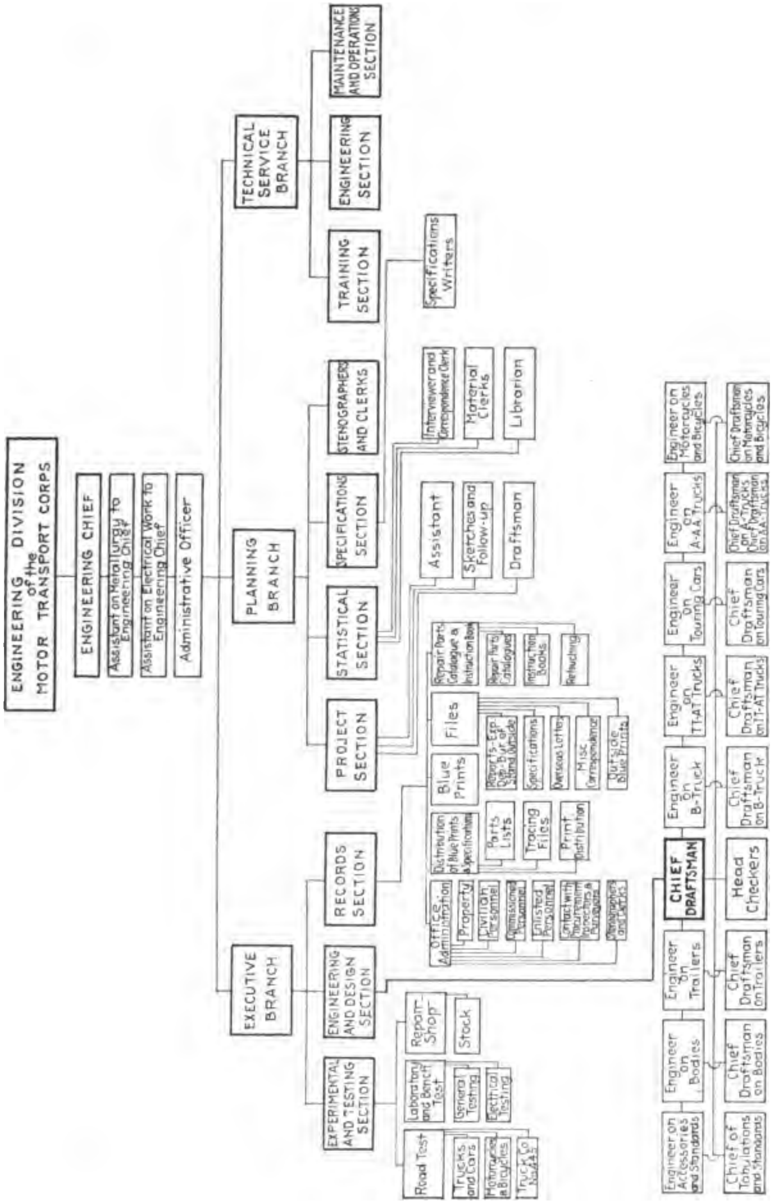

ENGINEERING DIVISION of the MOTOR TRANSPORT CORPS
ENGINEERING CHIEF
Assistant on Metallurgy to Engineering Chief
Assistant on Electrical Work to Engineering Chief
Administrative Officer
EXECUTIVE BRANCH
PLANNING BRANCH
TECHNICAL SERVICE BRANCH
EXPERIMENTAL AND TESTING SECTION
ENGINEERING AND DESIGN SECTION
RECORDS SECTION
PROJECT SECTION
STATISTICAL SECTION
SPECIFICATIONS SECTION
STENOGRAPHERS AND CLERKS
TRAINING SECTION
ENGINEERING SECTION
MAINTENANCE AND OPERATIONS SECTION
Road Test
Trucks and Cars
Motorcycles & Bicycles
Laboratory and Bench Test
General Testing
Electrical Testing
Repair Shop
Stock
Office Administration
Property
Civilian Personnel
Commissioned Personnel
Enlisted Personnel
Stenographers and Clerks
Distribution of Blue Prints & Specifications
Parts Lists
Tracing Files
Print Distribution
Blue Prints
Files
Specifications
Overseas Letters
Misc. Correspondence
Outside Blue Prints
Repair Parts Catalogue & Instruction Book
Repair Parts Catalogues
Instruction Books
Retouching
Assistant
Sketches and Follow-up
Draftsman
Interviewer and Correspondence Clerk
Material Clerks
Librarian
Specifications Writers
CHIEF DRAFTSMAN
Engineer on Accessories and Standards
Engineer on Bodies
Engineer on Trailers
Engineer on B-Truck
Engineer on TT-AT Trucks
Engineer on Touring Cars
Engineer on A-AA Trucks
Engineer on Motorcycles and Bicycles
Chief of Tabulations and Standards
Chief Draftsman on Bodies
Chief Draftsman on Trailers
Head Checkers
Chief Draftsman on B-Truck
Chief Draftsman on TT-AT Trucks
Chief Draftsman on Touring Cars
Chief Draftsman on Motorcycles and Bicycles

FIG. 132.

of the Engineering Division of the Motor Transport Corps of the Army is shown in Fig. 132.

Figure 133 is a chart of organization of the personnel of inspection of small arms accessories and was used by the writer in the control of inspection of accessories, appendages and boxes

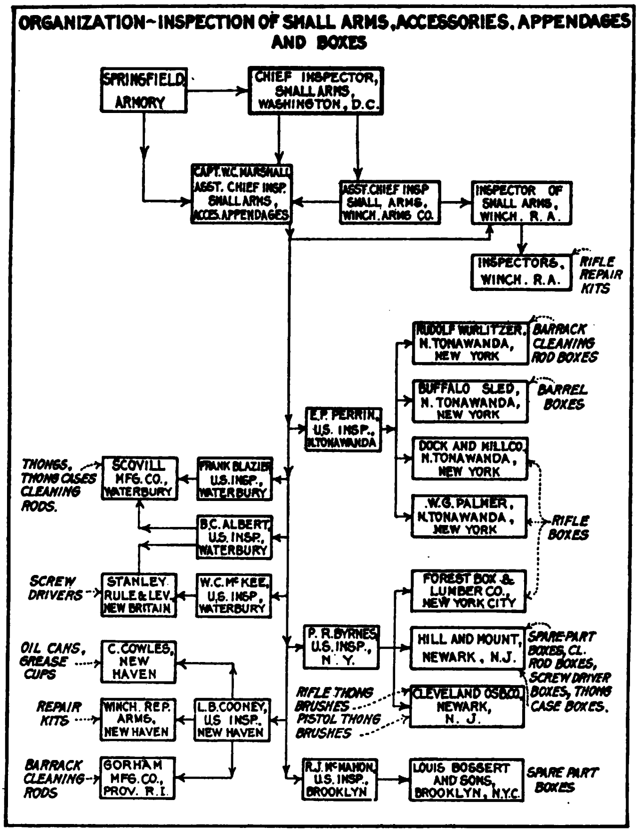


FIG. 133.—Organization chart of small-arms accessory and box inspection. Ordnance department, U. S. A., 1917.

pertaining to them. It gives at a glance the articles to be inspected, location of the shops making them, inspectors in charge of inspection at each one and the routing of orders from Washington and the Springfield Armory. A similar chart shown in Fig. 134 shows at a glance where various accessories and

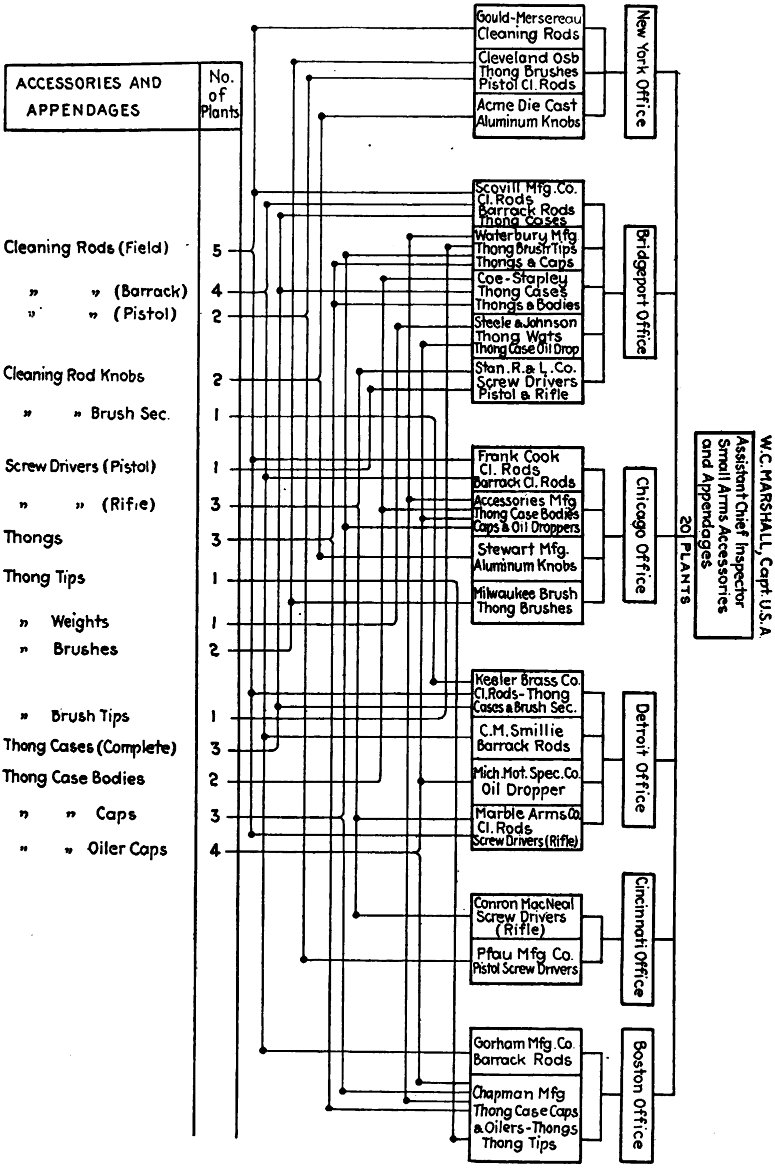
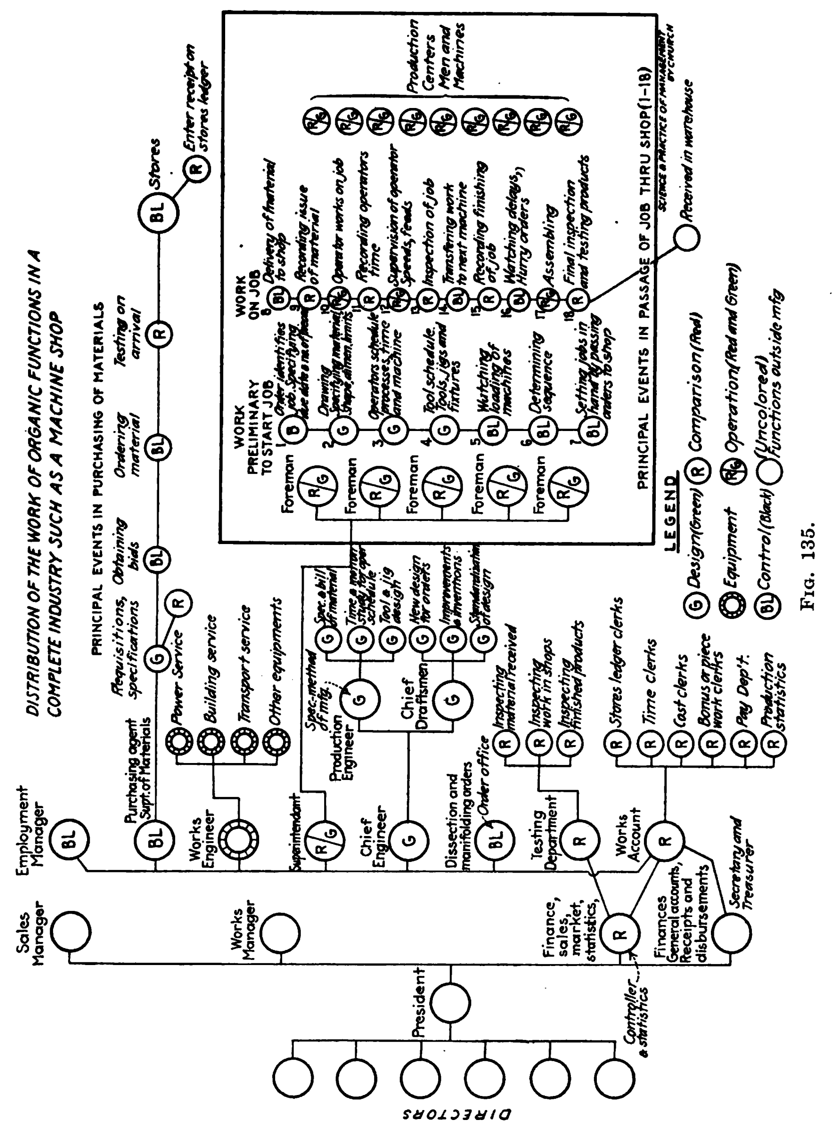

ACCESSORIES AND APPENDAGES
No. of Plants
Cleaning Rods (Field) 5
" " (Barrack) 4
" " (Pistol) 2
Cleaning Rod Knobs 2
" " Brush Sec. 1
Screw Drivers (Pistol) 1
" " (Rifle) 3
Thongs 3
Thong Tips 1
" Weights 1
" Brushes 2
" Brush Tips 1
Thong Cases (Complete) 3
Thong Case Bodies 2
" " Caps 3
" " Oiler Caps 4
Gould-Mersereau Cleaning Rods
Cleveland Osb Thong Brushes Pistol Cl. Rods
Acme Die Cast Aluminum Knobs
New York Office
Scovill Mfg. Co. Cl. Rods Barrack Rods Thong Cases
Waterbury Mfg Thong Brush Tips Thongs & Caps
Coe-Stapley Thong Cases Thongs & Bodies
Steele & Johnson Thong Wgts Thong Case Oil Drop
Stan. R. & L. Co. Screw Drivers Pistol & Rifle
Bridgeport Office
Frank Cook Cl. Rods Barrack Cl. Rods
Accessories Mfg Thong Case Bodies Caps & Oil Droppers
Stewart Mfg. Aluminum Knobs
Milwaukee Brush Thong Brushes
Chicago Office
Kesler Brass Co. Cl. Rods-Thong Cases & Brush Sec.
C.M. Smillie Barrack Rods
Mich. Mot. Spec. Co. Oil Dropper
Marble Arms Co. Cl. Rods Screw Drivers (Rifle)
Detroit Office
Conron MacNeal Screw Drivers (Rifle)
Pfau Mfg Co. Pistol Screw Drivers
Cincinnati Office
Gorham Mfg. Co. Barrack Rods
Chapman Mfg Thong Case Caps & Oilers-Thongs Thong Tips
Boston Office
20 PLANTS
W.C. MARSHALL, Capt. U.S.A. Assistant Chief Inspector Small Arms Accessories and Appendages

FIG. 134.



DISTRIBUTION OF THE WORK OF ORGANIC FUNCTIONS IN A COMPLETE INDUSTRY SUCH AS A MACHINE SHOP
PRINCIPAL EVENTS IN PURCHASING OF MATERIALS
Requisitions, Specifications
Obtaining bids
Ordering material
Testing on arrival
Stores
Enter receipt on stores ledger
Sales Manager
Employment Manager
Purchasing agent Supt. of Materials
Power Service
Building service
Transport service
Other equipments
Works Engineer
Works Manager
Superintendent
Production Engineer
Chief Engineer
Chief Draftsmen
Dissection and manifolding orders
Order office
Testing Department
Inspecting material received
Inspecting work in shops
Inspecting finished products
Works Account
Stores ledger clerks
Time clerks
Cost clerks
Bonus or piece work clerks
Pay Dep't.
Production statistics
Finance, sales, market, statistics,
Finances General accounts, Receipts and disbursements
Secretary and Treasurer
Controller & statistics
President
DIRECTORS
Foreman
WORK PRELIMINARY TO START JOB
WORK ON JOB
Production Centers Men and Machines
PRINCIPAL EVENTS IN PASSAGE OF JOB THRU SHOP (1-18)
Received in warehouse
LEGEND
Design (Green)
Comparison (Red)
Equipment
Operation (Red and Green)
Control (Black)
(Uncolored) functions outside mfg

FIG. 135.

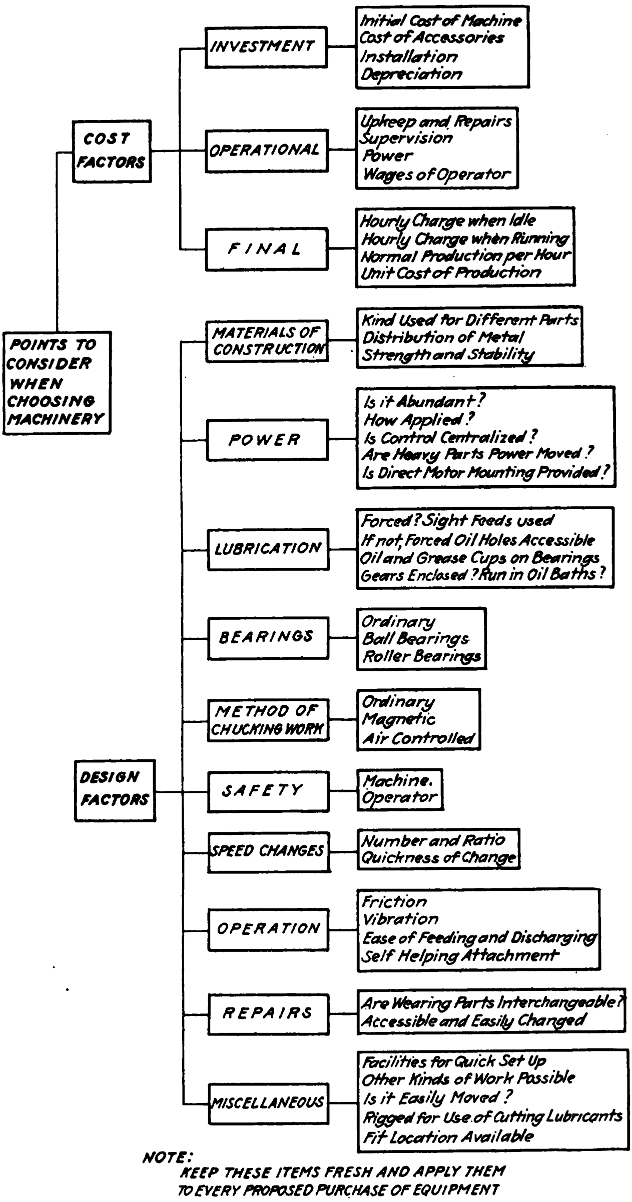

POINTS TO CONSIDER WHEN CHOOSING MACHINERY
COST FACTORS
INVESTMENT
Initial Cost of Machine
Cost of Accessories
Installation
Depreciation
OPERATIONAL
Upkeep and Repairs
Supervision
Power
Wages of Operator
FINAL
Hourly Charge when Idle
Hourly Charge when Running
Normal Production per Hour
Unit Cost of Production
DESIGN FACTORS
MATERIALS OF CONSTRUCTION
Kind Used for Different Parts
Distribution of Metal
Strength and Stability
POWER
Is it Abundant?
How Applied?
Is Control Centralized?
Are Heavy Parts Power Moved?
Is Direct Motor Mounting Provided?
LUBRICATION
Forced? Sight Feeds used
If not, Forced Oil Holes Accessible
Oil and Grease Cups on Bearings
Gears Enclosed? Run in Oil Baths?
BEARINGS
Ordinary
Ball Bearings
Roller Bearings
METHOD OF CHUCKING WORK
Ordinary
Magnetic
Air Controlled
SAFETY
Machine.
Operator
SPEED CHANGES
Number and Ratio
Quickness of Change
OPERATION
Friction
Vibration
Ease of Feeding and Discharging
Self Helping Attachment
REPAIRS
Are Wearing Parts Interchangeable?
Accessible and Easily Changed
MISCELLANEOUS
Facilities for Quick Set Up
Other Kinds of Work Possible
Is it Easily Moved?
Rigged for Use of Cutting Lubricants
Fit Location Available
NOTE:
KEEP THESE ITEMS FRESH AND APPLY THEM TO EVERY PROPOSED PURCHASE OF EQUIPMENT

FIG. 136A.

appendages for small arms were being made, the number of plants making each accessory and the district in which the plant was located. Such a chart is easily made and conveys much information in many different ways at a glance.

Figure 135 is an elaborate chart originally made in colors and used to show how the work is to be distributed in a machine shop.

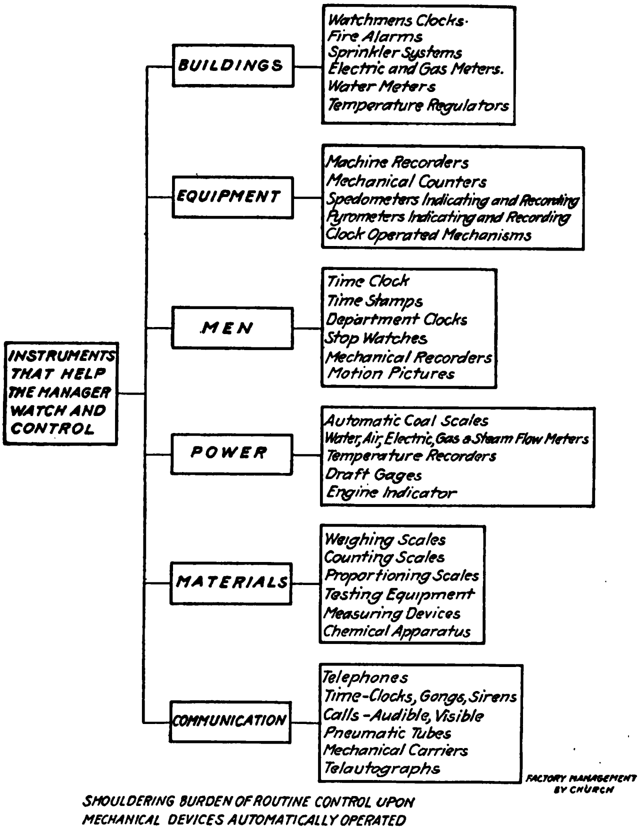
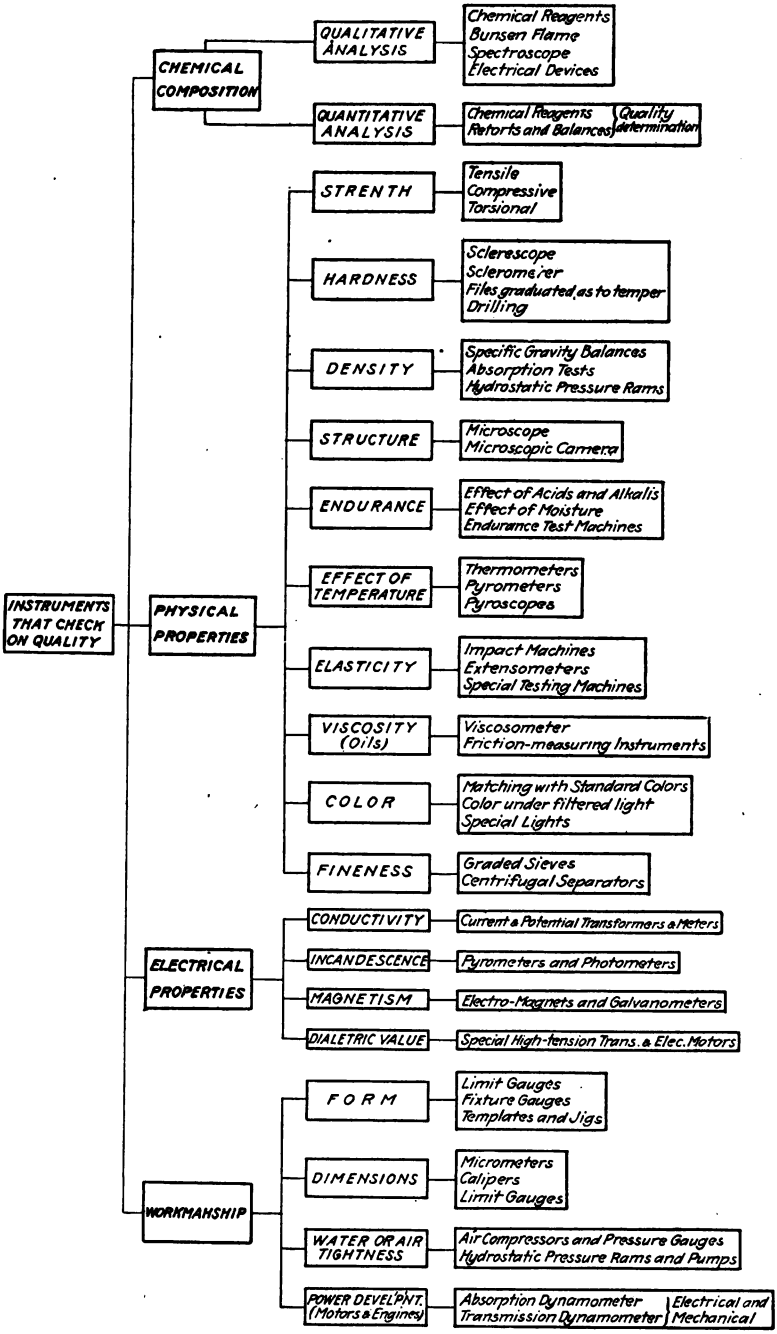


Fig. 136B.

R means red, *G* means green and *Bl* black in the circles where they appear. In Figs. 136 *A* and *B* and 137 will be found analysis diagrams of great use to executive, engineer or purchasing agent as they list in graphical form the important items to be considered in certain phases of shop management. This principle can be applied to other problems as they rise in the manager's office.



TECHNICAL CONTROL OVER PROPERTIES OF MATERIALS & ACCURACY OF WORKMANSHIP

FIG. 137.

CHAPTER VII

CALCULATIONS

In the preceding diagrams a straight line or broken line has been used to represent the law of variation, usually on a time basis. That is, for a given equal interval of time there is a corresponding happening of another quantity which is called a variable. When the equation of a line is of the form $y = ax + b$ the line is a straight line. For every value of x there is a corresponding value of y. If we give values to one variable we call them *independent* variables and the values of the other variable are called *dependent* variables. The value of the term b gives the point where the line cuts the vertical axis and the value of a determines the slope of the line. If we have one point on a straight line and its inclination we can draw the line.

In all of the preceding pages and examples the graphs have been drawn from tables or through points plotted from given data. We will now take up diagrams which are used in making calculations.

The two axes previously mentioned as the x- and y-axes are used in plotting the curves of the diagrams, the points of which are located by coordinates.

Diagrams for solving equations of a straight line such as $Y = A \pm BX$ are very common and usually of the form shown in Fig. 138. Here we have $Y = A \pm \left(\frac{m}{n}\right)x$; therefore $B = \frac{m}{n}$. If B changes, the slope of the line changes. If A is changed the line will move parallel to itself either up or down without changing its slope.

Suppose the type of equation is $Y = B(X \pm A)$ where A is a constant. Values of B are radial lines while the tangents of the angles C must be proportional to the values given to the corresponding radial lines. If $A = O$ the equation becomes $Y = BX$ and the radial lines meet at the zero point of the X and Y scales. Figure 139 is a diagram of this type suitable for the equation

$$Y = B(X - A) \text{ or } X = \frac{Y}{B} + A$$

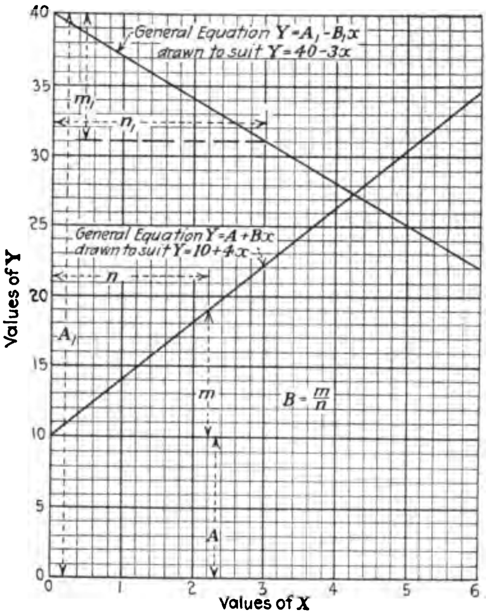
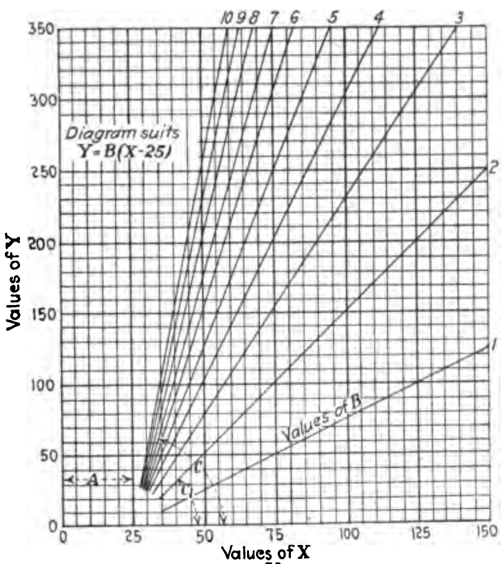


FIG. 138.



General Equation $X = \frac{Y}{B} + A$ or $Y = B(X-A)$

FIG. 139.

Applications of this diagram are numerous. As an example take the formula $T = \frac{P \times D}{S} + \frac{1}{8}$ in. for the thickness of pipes up to 15 in. when pressures vary from 200 to 400 lb. per square inch. S is assumed to be 10,000 lb. The formula can be expressed as

$$T = \frac{1}{8}\text{ in.} + \left(\frac{200}{10000}\right) D \text{ in which } A = \frac{1}{8}\text{ in. and } B = \frac{1}{50}$$

when $D = 15$, $T = \frac{1}{8}\text{ in.} + \frac{15}{50} = \frac{1}{8}\text{ in.} + \frac{3}{10}\text{ in.} = \frac{17}{40} = 0.425$ in.

For each value of P equal to 225, 250, 275, 300, 350 and 400 there will be a line drawn through a point $\frac{1}{8}$ in. to the right of the

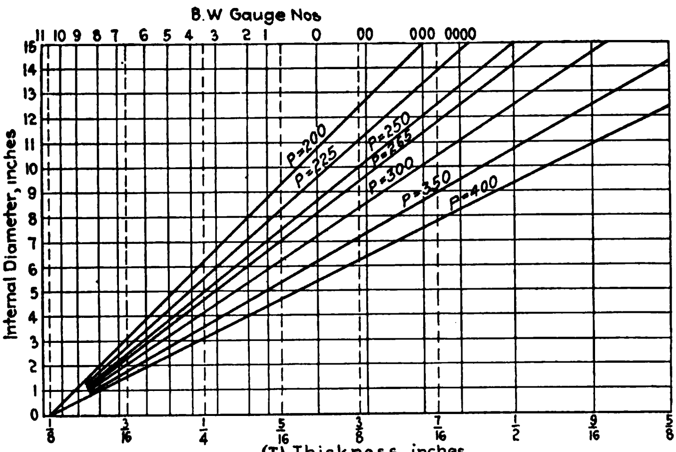


DIAGRAM FOR THICKNESS OF STEEL PIPES $T = \frac{P \times D}{10000} + \frac{1}{8}''$

FIG. 140.

Y-axis on the X-axis. The horizontal scale will be laid off from the Y-axis equal to thicknesses of pipe and Y, obtained from solutions of the above formula, will be laid off from the X-axis along the corresponding ordinate. One point on each of the lines will determine its slope as the lines all intersect the X-axis at a common point. The diagram will be like Fig. 140 when finished.

If the results of a set of experiments plot in a straight line, the equation to suit will be of the form $Y = A \pm BX$. If certain functions of x and y are plotted and a straight line results, the equation to suit these points will be as given in the following table:

Functions plotted		Equation to suit if plotted points lie in a straight line.
x	y	
Sin X	Y	$Y = A \pm B \sin X$
X^2	$\log Y$	$\operatorname{Log} Y = A \pm BX^2$
$\frac{1}{X}$	Y^3	$Y^3 = A \pm \frac{B}{X}$

Figure 141 is a diagram based on the above principles. It is for determining which cutter should be used to obtain the correct shape of teeth in a spiral gear when the number of teeth and

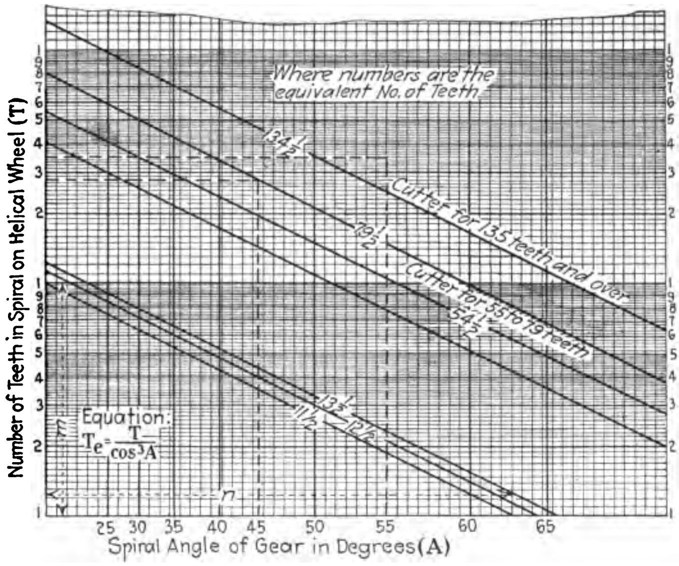


FIG. 141.

spiral angle are stated. The method adopted is to obtain the number of teeth for a spur gear to which it is equivalent and to use the spur gear cutter for that equivalent number of teeth. The formula governing this is $T_e = \frac{T}{\cos^3 A}$.

T_e = equivalent number of teeth in spur gear
T = number of teeth in spiral wheel
A = spiral angle of spiral wheel

If the equation is written $\log T = \log T_e + 3 \log \cos A$ it will be of the form $Y = A + BX$ and to obtain the straight line it will be necessary to plot $\log T$ and $\log \cos A$.

10

Again, $B = \frac{m}{n}$ (see Fig. 138). In this case $B = 3$.

$\therefore 3 = \frac{\text{actual length of } m \times 1/6}{\text{actual length of } n \times 1/36} \therefore \frac{\text{actual length of } m}{\text{actual length of } n} = 3 \times \frac{1/36}{1/6} = \frac{3 \times 1 \times 6}{36} = 1/2.$ We therefore mark off n on the diagram twice that of m and join them to obtain the slope of the lines. The sloping lines bear the same number as their point of intersection on the T-scale.

The values of the sloping lines have been selected to agree with the limits adopted by the cutter manufacturers, *viz.*, No. 1 cutter 135 teeth and over, No. 2 cutter 55 to 79 teeth.

The chart is used thus: Given a spiral gear of 35 teeth and spiral angle of 55°, what cutter is necessary? Using dotted lines it is found that the point lies within the limits for a cutter for 135 teeth and over. If the equivalent number of teeth was required it would be necessary to draw more sloping lines parallel to the others and numbered like their points of intersection with the T-scale.

In order to construct the chart it is first of all necessary to know between what limits the chart is to be used. In this case we will take A from 0 to 65° and T from 1 up to 100 teeth. The variation on the T-scale will be log 100 − log 1 = 2, and by making 1 in. = 1/6 unit the total length of T-scale will be 12 in. The variation on the A-scale will be log cos 65° − log cos 0° = −0.374 − 0 = −0.374. If 1 in. = 1/36 unit the total length of A-scale will be −13.46 in. By comparison with the equation $Y = A + BX$, log T will take the Y position and log cos A will take the X position. As values of log cos A are negative they will be read off to the left. Draw OC and OD as axes, mark off points and number them from the following tables:

T	Log T	Length of ordinate: 6 log T	$A°$	Log cos $A°$	Length of abscissa: 36 log cos $A°$
1	0	0	0	0	0
12	1.079	6.475 in.	30°	−0.062	− 2.25 in.
40	1.602	9.612 in.	45°	−0.151	− 5.42 in.
90	1.954	11.725 in.	65°	−0.374	−13.46 in.

The sloping lines 11½, 12½, 13½ . . . 134½ are the straight lines plotted to suit the equation $\log T = \log T_e + 3 \log \cos A$ but with T_e taking the values 11½, 12½, 13½ . . . 134½. By referring to Fig. 138 it will be seen that this amounts to a change of A in that diagram, the slope remaining constant. Figure 142 embodies the same principles as Fig. 139. Formula is

$$D^3 = \frac{d_1^4 - d_2^4}{d_1}$$

D = diameter of solid shaft
d_1 = outside diameter hollow shaft
d_2 = bore of hollow shaft

Equation may be written $D^3 \times d_1 = d_1^4 - d_2^4$.

Bottom scale for D^3 is 1 in. = 1,000 units.

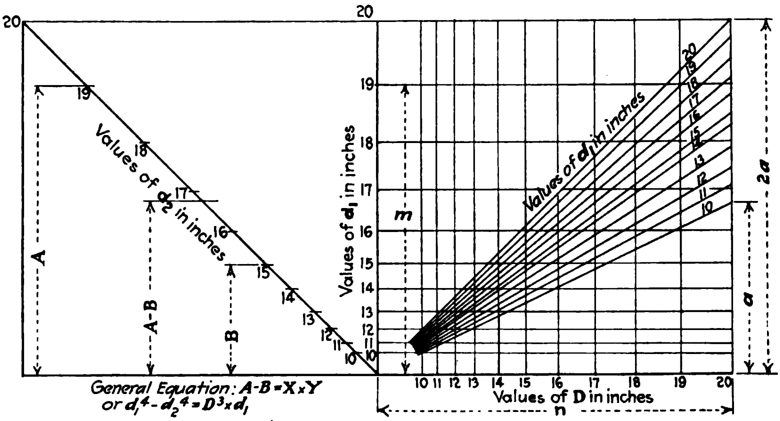


FIG. 142.

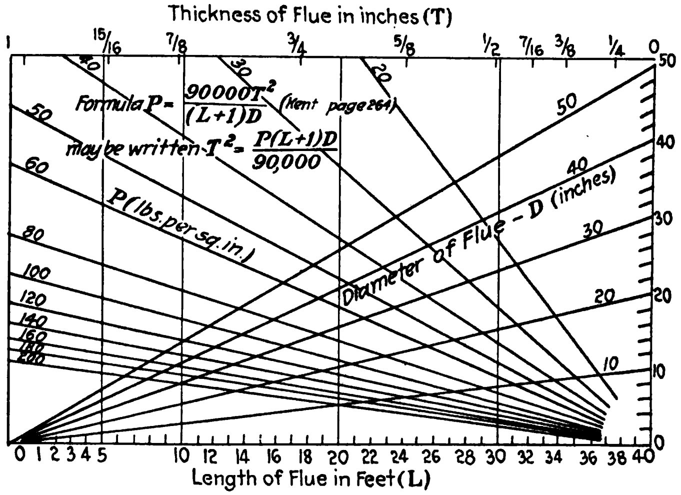
For example, when D = 20 in. D^3 = 8,000 and n = 8 in. Radial lines are drawn so tangents of angle with horizontal are proportional to values assigned them. Commence with d_1 = 20 line and work down.

On vertical center line of diagram values of d_1^4 have been set off to a scale of 1 in. = 20,000 units. For example, for d_1 = 19, d_1^4 = 130,321, m = 6.516 in. long. Values of d_2 are shown on an inclined line whose angle does not matter but is preferably 45°. Vertical height of d_2 is same as d_1 and has 20,000 units per inch same as d_1. By this means d_2^4 can be subtracted from d_1^4 but with some assistance from the inclined lines at the left. If A represents d_1^4 and $B = d_2^4$ then the length B must be subtracted at the top end to give a reading starting at 0 which will be common to the right-hand portion of the diagram.

To use chart:

(1) Given 20-in. shaft, what diameter hole can be put through it to have same strength as a 16-in shaft? Erect perpendicular at 16 to meet inclined 20, move horizontally to d_2 line for answer = 16.7.

2. What size solid shaft is equivalent in strength to a hollow shaft 19-in. outside drameter, 15-in. bore? At $d_2 = 15$ erect vertical line to horizontal $d_1 = 19$, then horizontally to radial 19 and drop vertical to D for answer = 16.1.



STRENGTH OF BOILER FLUES

Fig. 143.

Another chart of type similar to Fig. 140 is used to determine the thickness of boiler flues. This is shown in Fig. 143. The formula is $P = \dfrac{90{,}000\,T^2}{(L+1)D}$ where P = working pressure in pounds per square inch, L = length of flue in feet.

Logarithmically ruled paper can be used instead of squared paper when the logs of a number have to be plotted. Figure 144 shows this general equation $y = bx^a$ or $\log y = \log b + a \log x$. This chart is drawn for $y = bx.^2$

This follows the type shown in Fig. 138. It can also be used as a slide rule scale to find the value of a series of numbers which are in geometrical progression. As an example find 10 numbers in geometrical progression commencing at 1.3 and finishing at 6.

Divide the distance between these points into one less than the number of terms required (9) and the values can be read off directly.

Another type of chart is based on the law of similar triangles $\frac{L}{K} = \frac{N}{M}$ and any equation resolved into this form can be solved by this type of chart, as in Fig. 145.

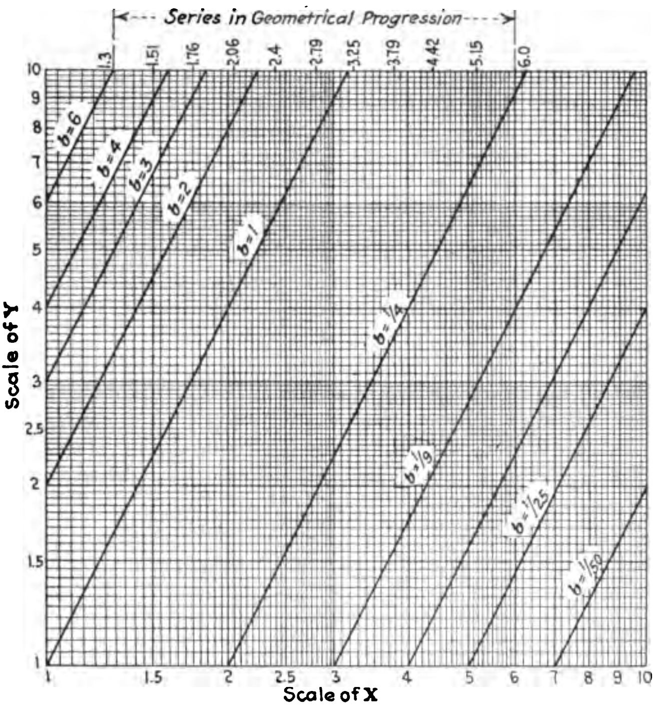


FIG. 144.

For example, $\frac{D^2}{V} = \frac{HP.}{0.0607.\left(\frac{U}{100}\right)^3}$ for finding frictional horsepower at disc when rotating in steam. Used in steam-turbine work.

This formula can be written $\frac{0.0607D^2}{V} = \frac{HP.}{\left(\frac{U}{100^3}\right)}$ similar to $\frac{L}{K} = \frac{N}{M}$.

HP . = disc frictional horsepower
D = mean ring diameter in feet
U = mean blade speed feet per second
V = specific volume of steam in cubic feet.

To use chart: (1) connect values of V and D; (2) draw a parallel to this from U to give horsepower.

Scale of V. 1 in. = 20 units
Scale of D^2. 1 in. = 1 unit
Scale of $0.0607\left(\frac{U}{100}\right)^3$. 1 in. = 20 units
Scale of HP. 1 in. = 1 unit

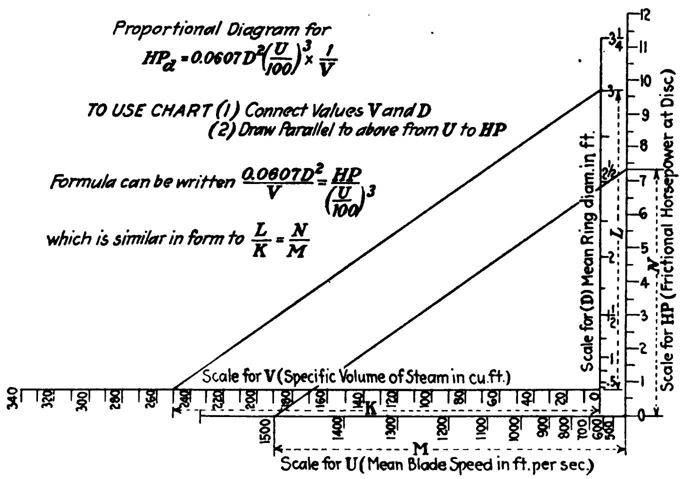


FIG. 145.

This is equivalent to expressing the equation $\frac{D^2}{\frac{1}{20}V} = \frac{HP}{0.003035\left(\frac{U}{100}\right)^3}$ from which the point marked 1,000 on the U-scale will be $0.003035(10^3) = 3.035$ in. from zero point.

Another diagram of the proportional type is based on $K + L = M + N$. It can be applied to the plotting of logs of the variables as $\log K + \log L = \log M + \log N$ or $KL = MN$. If the equation of Fig. 145 is written in this manner $\log HP. + \log V = 2 \log D + (3 \log U - (6 - \log 0.0607))$. This must be

multiplied by 2 to make the diagram easier to read, from which we have 2 log $HP.$ + 2 log V = 4 log D + (6 log U − 14.43). This has been plotted in Fig. 146, $HP. = 0.0607D^2\left(\frac{U}{100}\right)^3 \times \frac{1}{V}$. Formula may be written log $HP.$ + log V = 2 log D + (3 log U + 8.7831). To use chart join values of U and D and draw parallel to above from V to give $HP.$

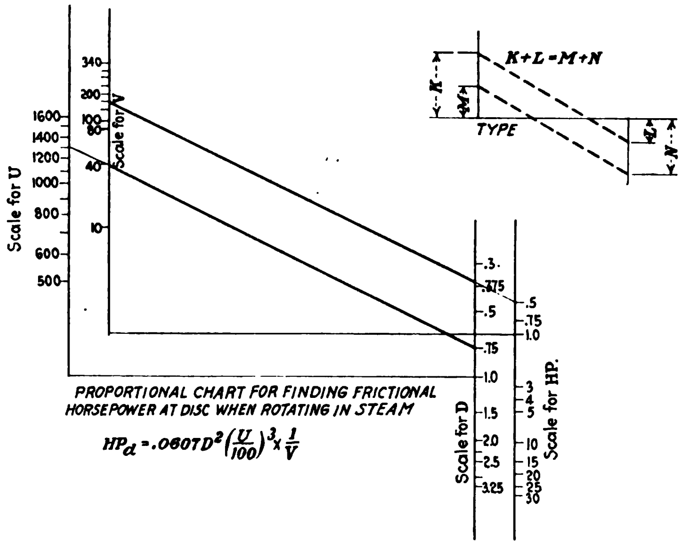


FIG. 146.

This table gives a few of the values marked off:

$HP.$	2 log $HP.$	V	2 log V	D	4 log D	U	6 log U −14.43
1	0	10	2	0.3	$\bar{3}$.91	500	1.76
0.5	$\bar{1}$.40	200	4.60	1.5	0.70	1,000	3.57
20	2.60	340	5.063	2.5	1.59	1,500	4.62

Minus characteristics and mantissa may be laid off on opposite sides of the zero mark.

Still another chart of proportional type can be used for proportioning boiler flues, Fig. 147. The formula is $P = \frac{90{,}000T^2}{(L+1)D}$, which is written log P + 4 log D = (8 log T + 4 log 90,000) −

4 log $(L + 1)$. P should read to 200 lb. pressure and log 200 = 2.301. We can make 1 in. = ¼ unit or multiply equation by 4. This is the same formula as used for Fig. 143 but the diagram is easier to construct although not so easy to use.

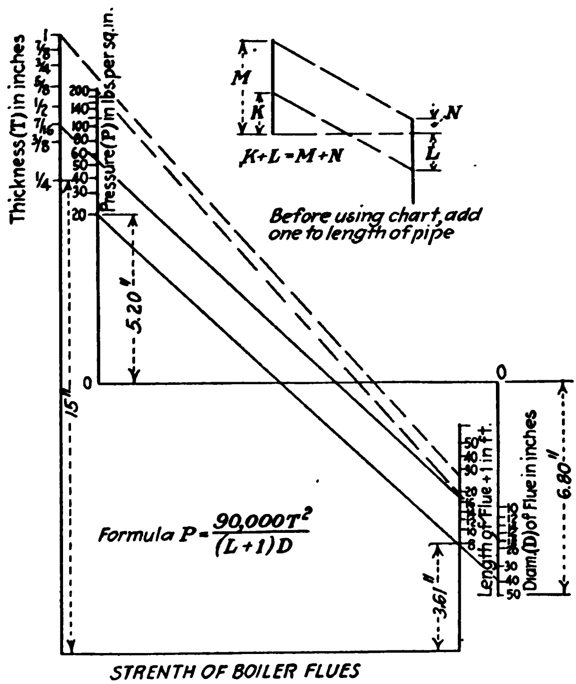


FIG. 147.

A similar chart can be constructed when there are three variables instead of four as in the formula for collapsing pressure for Bessemer steel tubes (see Fig. 148). $P = 50{,}210{,}000 \left(\frac{t}{D}\right)^3$ when P is less than 580 lb. per square inch and length of tube is over 6 times the diameter. The equation rewritten is 3 log D + log P = log 50,210,000 + 3 log t. In the chart the third scale becomes a common point for all values as the third variable is now a fixed quantity log 50,210,000. To use chart connect D with P. Draw parallel from O to find t.

Z diagrams are used for a different form of equation from those

preceding. These forms are $A + B = \frac{X}{Y}$ and the diagram Fig. 149 shows how the formula is applied.

$$\frac{K}{D} = \frac{L}{C} \quad \therefore \quad K = \frac{LD}{C}$$

$$K + L = \frac{LD}{C} + L = \frac{L}{C}(D + C) = \frac{M}{N}(D + C)$$

$$\therefore \quad K + L = \frac{M}{N} \text{ (length of diagonal)}$$

general equation $A + B = \frac{X}{Y}$

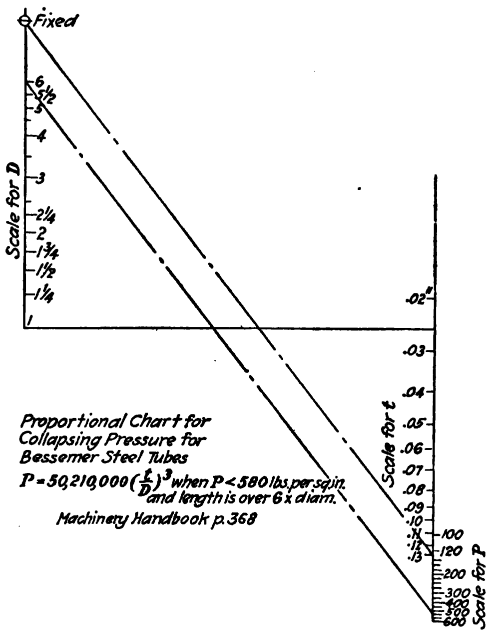


Fig. 148.

Where K represents A, L represents B.
M represents X, N represents Y.
Scales: 1 in. on scale A represents R units.
then 1 in. on scale B represents R units.
Let 1 in. on scale X represent S units.
Let 1 in. on scale Y represent T units.

$$\text{then } K = \frac{A}{R}, \quad L = \frac{B}{R}, \quad M = \frac{X}{S}, \quad N = \frac{Y}{T},$$

$$\therefore \quad \frac{A}{R} + \frac{B}{R} = \frac{X}{S} \times \frac{T}{Y} \text{ (length of diagonal)}$$

$$\therefore \quad \frac{A+B}{R} = \frac{X}{Y}\left(\frac{T}{S}\right) \text{(length of diagonal)}$$

$$\therefore \quad \frac{1}{R} = \frac{T}{S} \text{ (length of diagonal)}$$

$$\therefore \text{ Length of diagonal } = \frac{S}{R \times T}$$

Slope of diagonal is best at about 45° but its length is important.

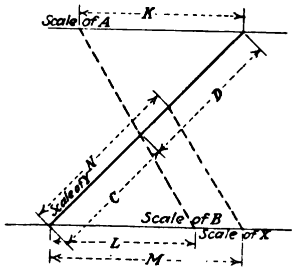


FIG. 149.

Such a formula as $P = \frac{1.24D^2}{T} + D$ can be used on the Z diagram for finding the pitch of units in double-riveted lap joints (plate at 56,000 lb. and rivets 18,000 lb. per square inch., Kent, p. 358).

D = diameter of rivets
T = thickness of plate

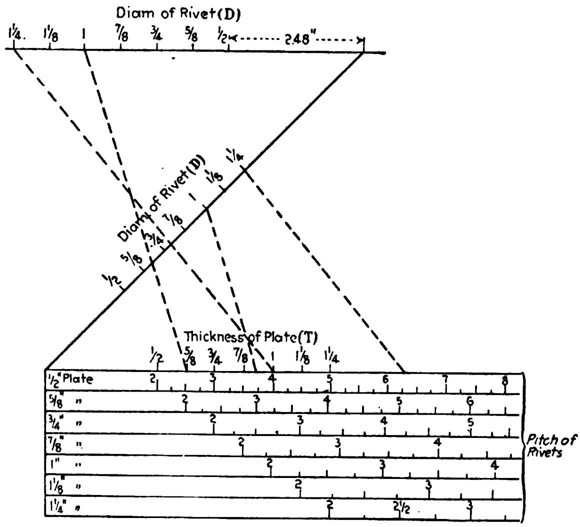
This formula may be written $1.24D + T = \frac{PT}{D}$. In Fig. 150 place $1.24D$ values on top line, values of T on upper side of lower line of Z, values of D on the diagonal; then values of $P \times T$ will be on lower side of lower bar of Z. As values of P are required, different scales are given for different values of T.

Scales of chart:

1 in. on 1.24 D scale = ¼ unit
1 in. on T scale = ¼ unit
1 in. on D scale = ¼ unit
1 in. on $P \times T$ scale = ½ unit

$$\text{Length of diagonal necessary} = \frac{\frac{1}{2}}{\frac{1}{4} \times \frac{1}{4}} = \frac{\frac{1}{2}}{\frac{1}{16}} = 8 \text{ in.}$$

Distance to ½-in. division on top line of $Z = 1.24 \times 0.5 \times 4 = 2.48$ in.



PITCH OF RIVETS FOR DOUBLE RIVETTED LAP JOINTS

Fig. 150.

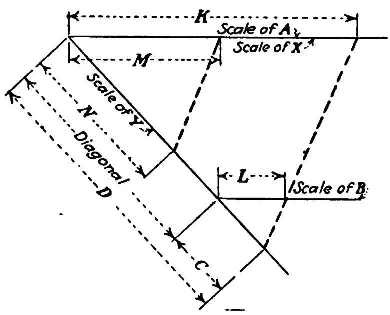


Fig. 151.

Draw a line from D on top line to T on upper side of lower line. From D on diagonal draw parallel to meet lower line of Z. Drop vertical to scale for size plate used (for 28 tons in plate and 24 tons in rivets, Kent, p. 358).

Another type of Z diagram is used when the type of equation is $A - B = \frac{X}{Y}$. Theory of diagram shown in Fig. 151.

$$\frac{K}{D} = \frac{L}{C} \quad \therefore \quad K = \frac{LD}{C}$$

$$K - L = \frac{LD}{C} - L = \frac{L}{C}(D - C)$$

$$= \frac{M}{N}(D - C)$$

$$\therefore K - L = \frac{M}{N} \text{ (length of diagonal)}$$

General equation $A - B = \frac{X}{Y}$

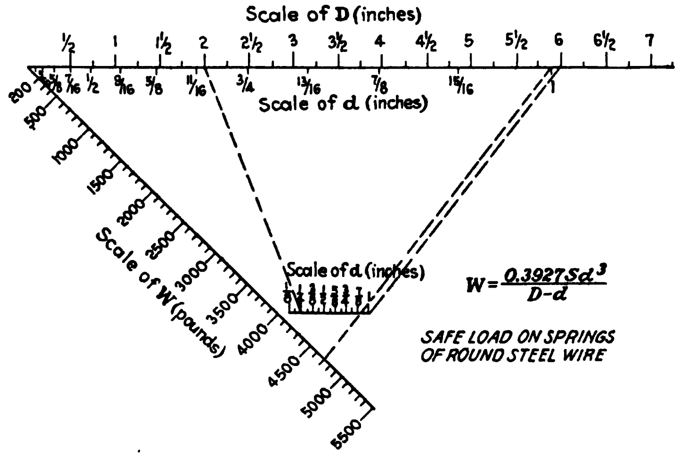


FIG. 152.

When K represents A, L represents B.
M represents X, N represents Y.

Scales: Let 1 in. on scale $A = R$ units
then 1 in. on scale B must $= R$ units
Let 1 in. on scale X represent S units
Let 1 in. on scale Y represent T units

then length of diagonal $= \frac{S}{R \times T}$

Using above principle lay out Z diagram for $W = \frac{0.3927Sd^3}{D - d}$.

S taken as 60,000 before charting, then $D - d = \frac{23,562d^3}{W}$.

Safe load on springs of round steel wire, Fig. 152.

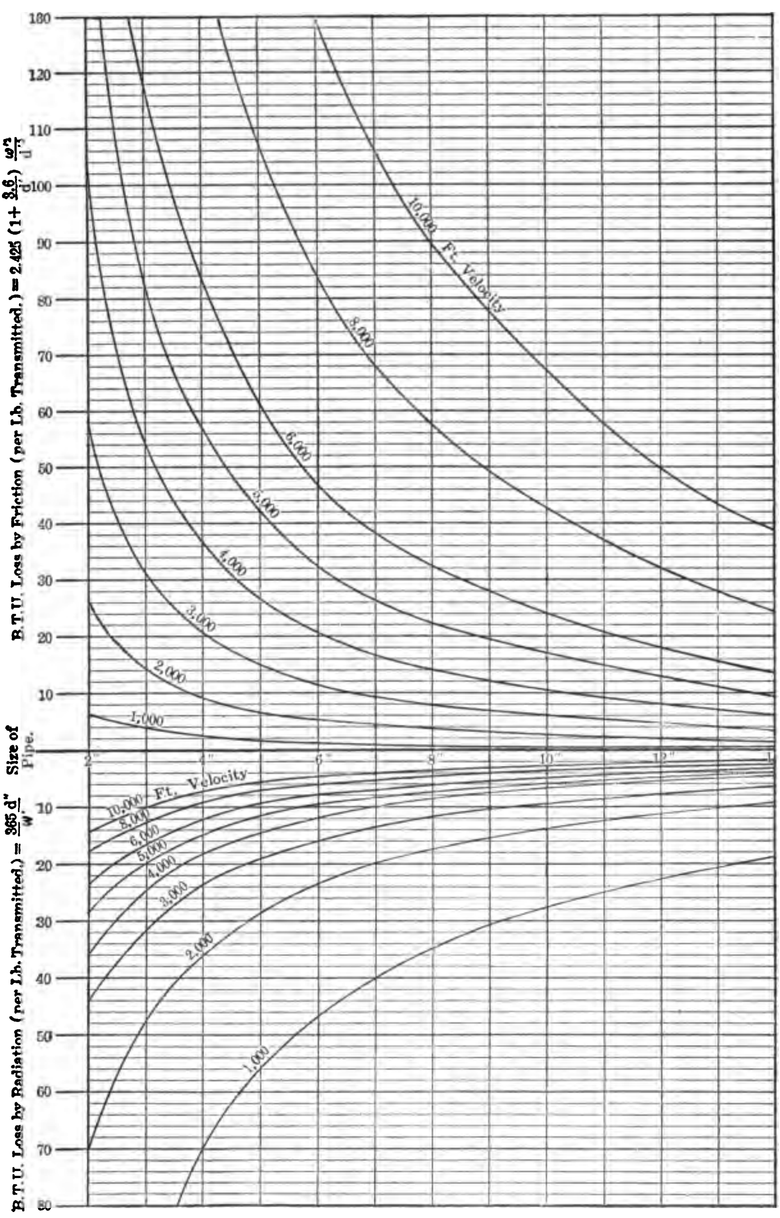


Fig. 153.—Losses by friction per 1000 feet of pipe. Noncondensing conditions.

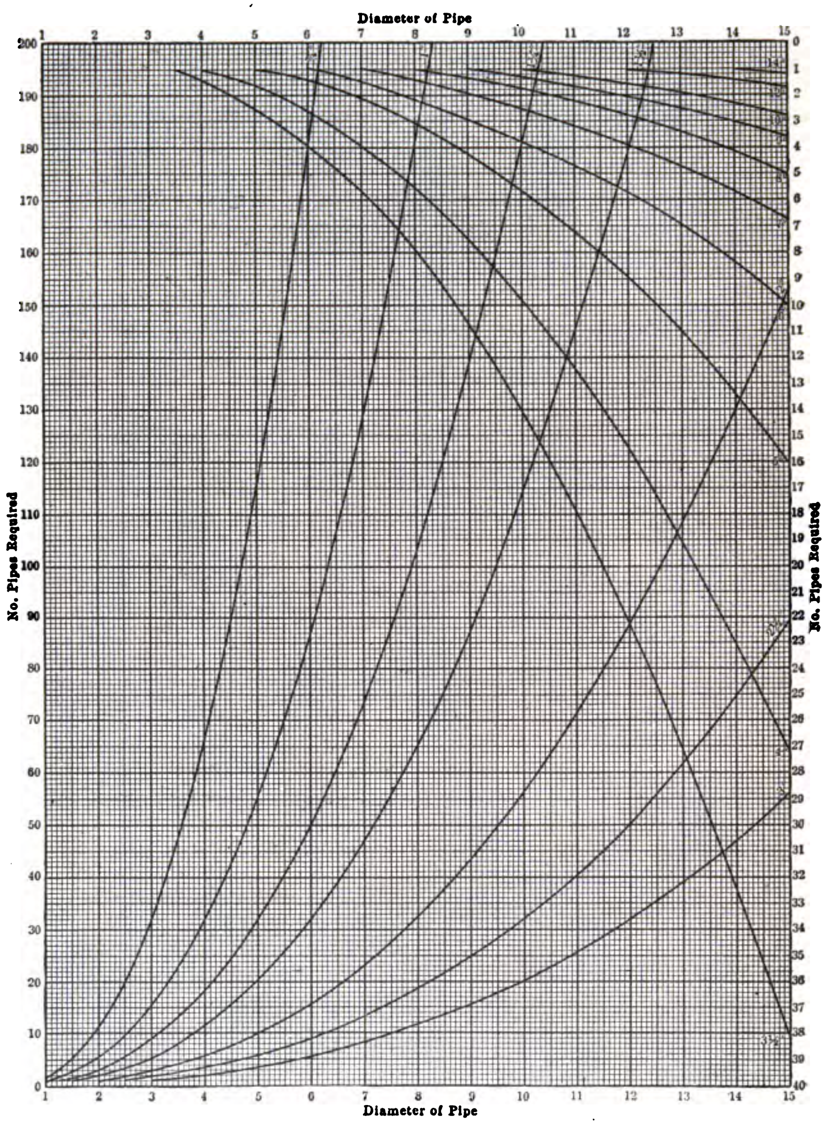


DIAGRAM FOR THE PROPORTIONING OF PIPING SYSTEMS

Fig. 154.—Diagram for the proportioning of piping systems.

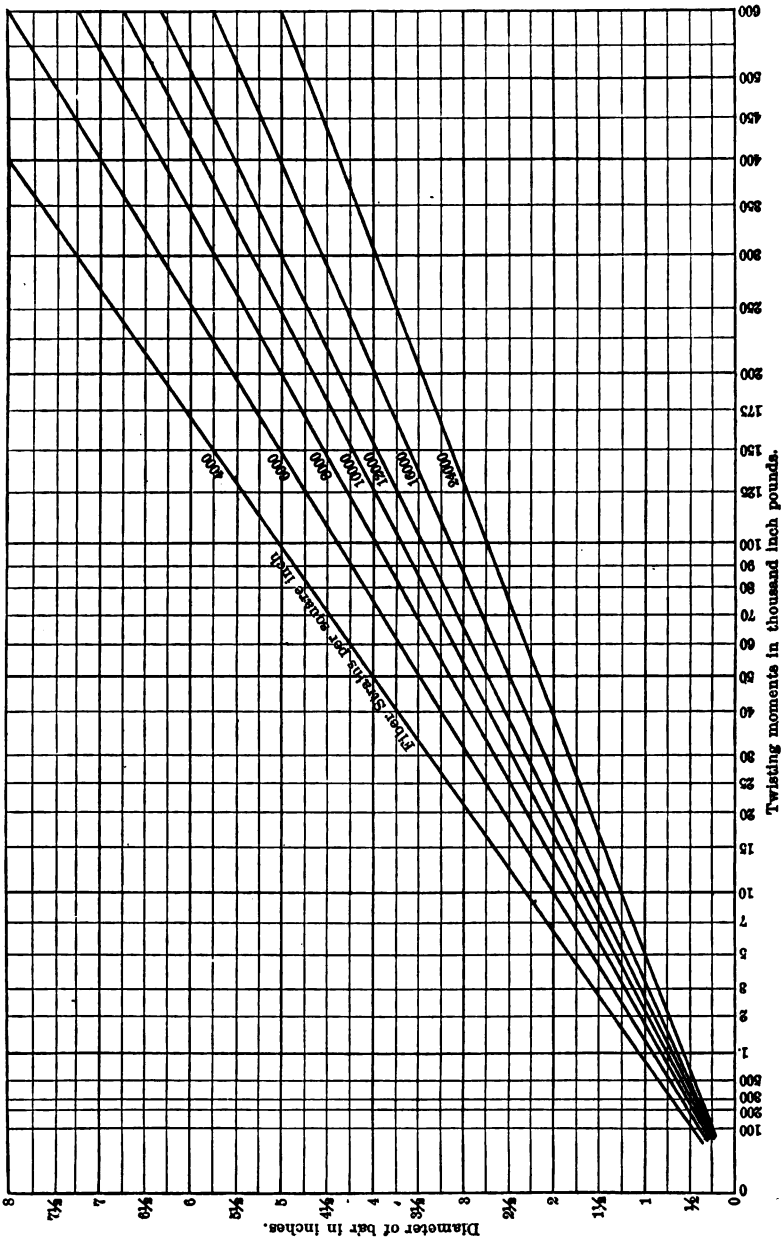


FIG. 155.—Diagram of torsional shearing strength of round shafts for different fibre strains per square inch.

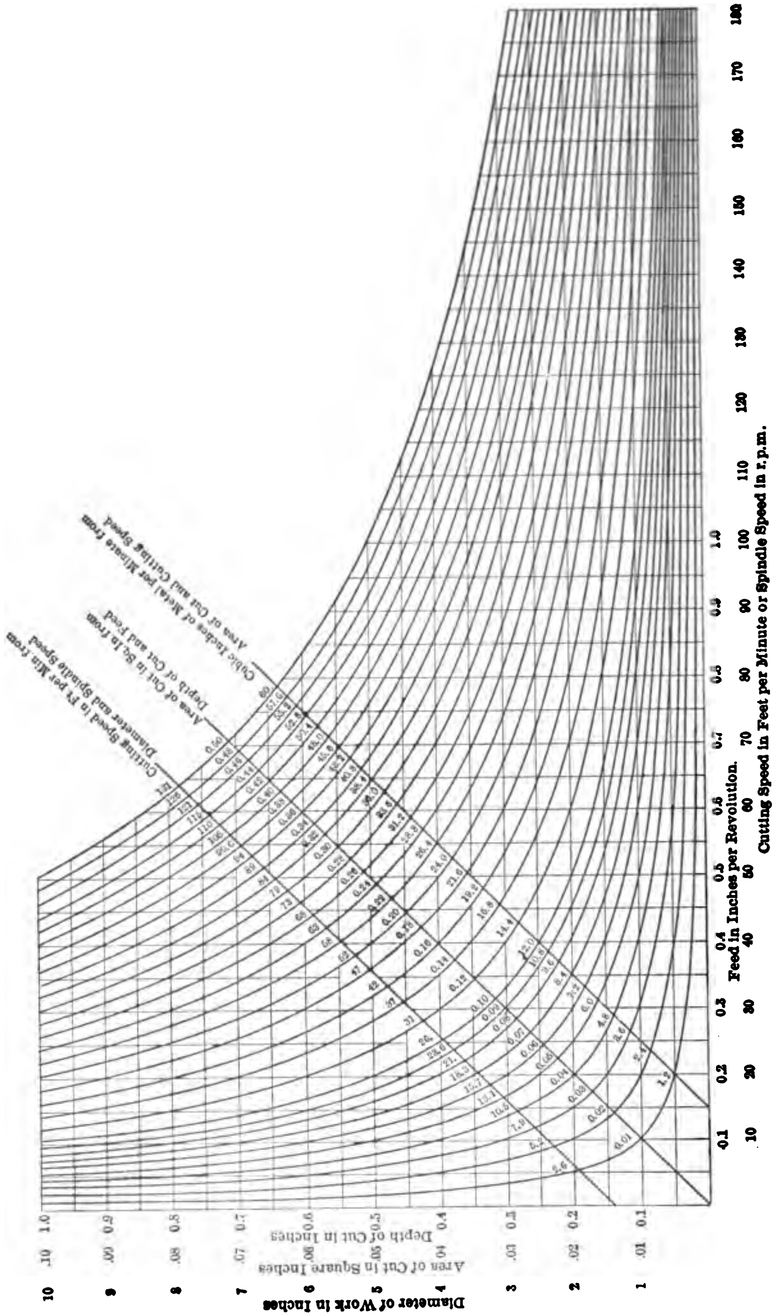


FIG. 156.—Machine tool calculator for lathes, planers, shapers, slotters and boring mills.

Scales adopted: 1 in. = ½ unit on D scale and lower d scale

1 in. = 2,000 units on upper d scale

1 in. = 500 units on W scale

$$\text{Diagonal} = \frac{2{,}000}{\frac{1}{2} \times 500} = \frac{2{,}000}{250} = 8 \text{ in.}$$

To use, join D to lower d and from upper d draw a parallel to this line to meet W in required value.

In order to present forms of calculating diagrams used by engineers the author has selected a few which have been taken from the current periodicals and cover a diversified range of application.

Figure 153 is used to obtain the friction and radiation losses per thousand feet of pipe. The friction loss is calculated from the formula $H^1 = f\dfrac{2v^2}{gdWL}$ where

d = diameter of pipe in feet.

L = length of pipe in feet (including equivalent length for ells and globe valves).

v = velocity in feet per second.

W = pounds of steam flowing per hour.

The diagram was constructed from the British thermal unit loss by friction (per pound transmitted) $= 2.425\left((1 + \dfrac{3.6}{d_1}\right)\dfrac{W_1{}^2}{d_1{}^5}$

d_1 = diameter of pipe in inches.

W_1 = pounds of steam flowing per minute.

DIRECTIONS FOR USING FIG. 156

(*a*) To find cutting speed: From intersection of horizontal line corresponding to diameter and vertical line corresponding to spindle speed, follow nearest curve and use value found in oblique line of figures marked cutting speed.

(*b*) To find area of cut: From intersection of horizontal line corresponding to depth of cut and vertical line corresponding to feed, follow nearest curve and use value found in oblique line of figures marked area of cut.

(*c*) To find cubic inches of metal removed per minute: From intersection of horizontal line corresponding to area of cut and vertical line corresponding to cutting speed follow nearest curve and use value found in oblique line of figures marked cubic inches of metal removed per minute.

To use curve, knowing diameter of work, spindle speed, depth of cut and feed, find cutting speed from (*a*) area of cut from (*b*) and cubic inches of metal removed per minute from (*c*).

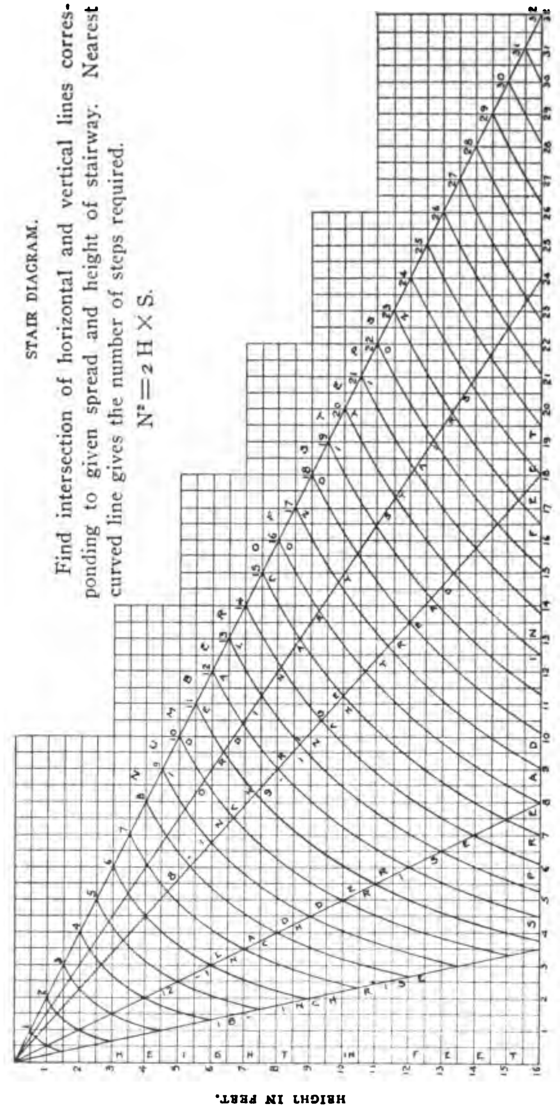


FIG. 157.—Stair diagram for number of steps when spread and height of stairway are given.

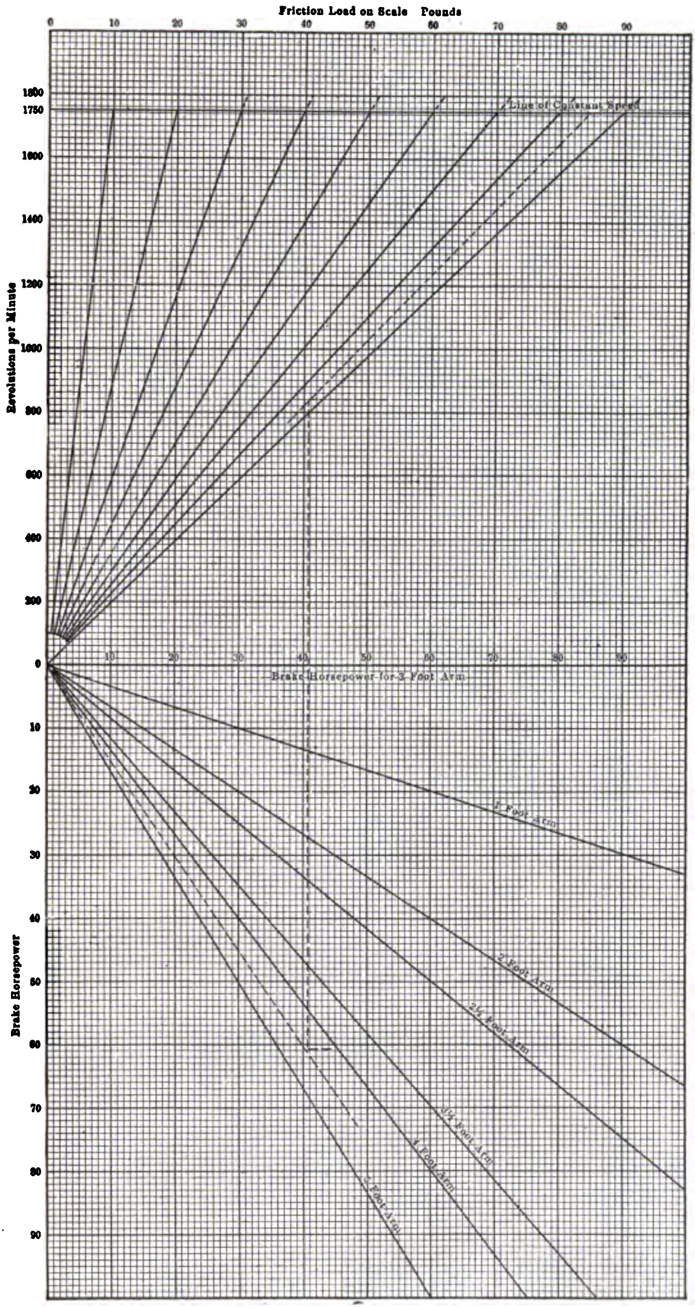


FIG. 158.—General Prony-brake curves.

The loss by radiation (B.t.u.) per pound transmitted $= \dfrac{365d_{11}}{W_1}$

d_{11} outside diameter of pipe in inches.
W_1 = pounds steam flowing per minute.

Radiation losses per hour in B.t.u.'s are expressed by $U = \pi d_{11}Lc(T_s - T_o)$ where d_{11} = outside diameter of pipe in inches. c = constant,

T_s = temperature of steam
T_o = temperature of room

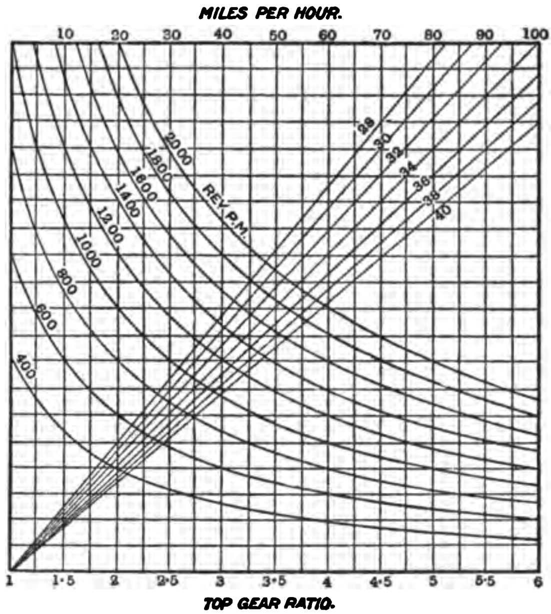


FIG. 159.—Curves from which, when the details of any three are known, either the engine speed, speed of the car in miles per hour, wheel diameter, or gear ratio may be obtained.

In Fig. 154, a ready means is given of finding the number of pipes equivalent to a pipe of given size. It may be used to find the size of pipe equal to any other two or more sizes and is used in the proportioning of pipe lines. The basis of construction is the formula for volume in cubic feet of water delivered by a pipe, *viz.*, $q = 0.7854\sqrt{\dfrac{2\,ghd^5}{1.5\,d + fL}}$

In Fig. 155 is shown a diagram used in finding the diameter of shafts when the torsional moments and unit stresses are known.

DIAGRAMS FOR CALCULATING PERCENTAGE OF STRENGTH OF RIVETED JOINTS.

FORMULÆ.

$\frac{P-D}{P} \times 100 = S$. Lloyd's and Board of Trade.

Board of Trade.

$\frac{A \times N}{P \times T} \times 100 = S_1$ for iron plates and iron rivets.

$\frac{A \times N \times 23}{P \times T \times 28} \times 100 = S_1$ for steel plates and steel rivets.

$\frac{A \times N \times 8}{P \times T \times 13} \times 100 = S_1$ for steel plates and iron rivets.

Lloyds.

$\frac{A \times N}{P \times T} \times 100 = S_1$ for iron plates and iron rivets. {punched holes.

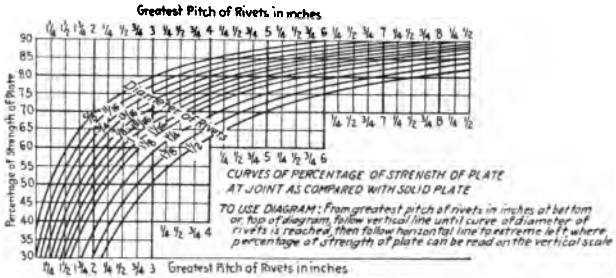
$\frac{A \times N}{P \times T} \times 90 = S_1$ for iron plates and iron rivets. {drilled holes.

$\frac{A \times N}{P \times T} \times 85 = S_1$ for steel plates and steel rivets.

$\frac{A \times N}{P \times T} \times 70 = S_1$ for steel plates and iron rivets.

WHERE

P = Greatest pitch of rivets in inches.
D = Diameter of rivets.
A = Area of rivets.
N = Number of rivets in one pitch.
T = Thickness of plates in inches.
S = Percentage of strength of plate at joint.
S_1 = Percentage of strength of rivets at joint.



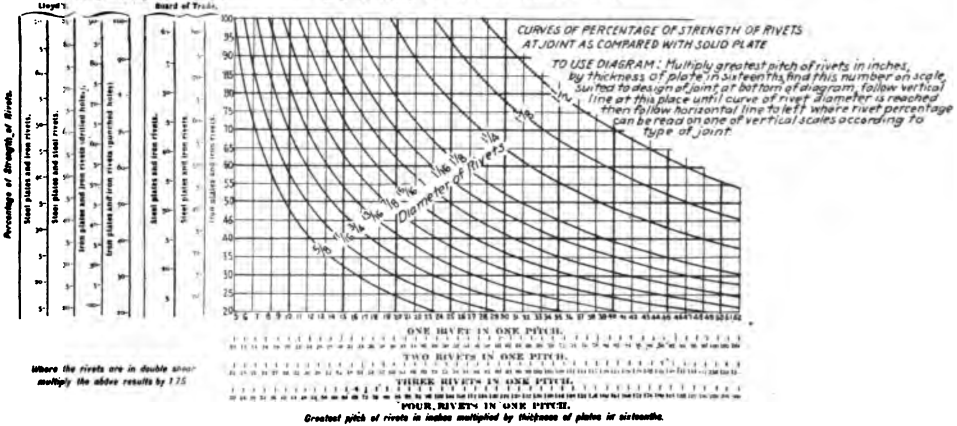


FIG. 160.

The horizontal scale is logarithmic and the vertical scale arithmetic otherwise the diagonal lines would be curved as those of Fig. 154.

Figure 156 is a diagram for making various calculations in connection with the removal of metal by different kinds of machine tools. Directions for use are given below it.

Figure 157 is a diagram used to compute the number of steps in a flight of stairs when the total horizontal and vertical lengths of the stairway are known. The product of rise and tread equals 72.

Figure 158 is a diagram used to find the horsepower from the revolutions per minute, friction load and length of brake arm of a Prony brake. By means of this diagram the horsepower for any length of brake arm can be reduced to the 3-ft. arm or it can be used to find the horsepower for any length of brake arm by drawing a line on the diagram for that particular arm. Horsepower $= \frac{2\pi RNW}{33{,}000}$

R = length of brake arm.
H = revolutions per minute. $\pi = 3.1416$
W = friction load on scale pan.

Figure 159 is a diagram for finding the engine speed per minute when the road speed is known. It is necessary to know the wheel diameter and gear ratio on direct drive. Gear ratios are given along the bottom scale and miles per hour on the top scale. To find revolutions per minute when gear ratio, wheel diameter and miles per hour given. Find number on top line corresponding to miles per hour and drop vertically to cut the line of wheel diameter. Then move along horizontally to meet the vertical line through the given gear ratio. The nearest curved line to the point of intersection of these vertical and horizontal lines will be the revolutions per minute. A conversion table for millimeters and inches in the diameter of wheels is also given.

Figure 160 is a diagram for calculating rivetted joints, for different kinds of joints, rivets and plates. The rules from which the diagrams were drawn are in use by Lloyds and the English Board of Trade. Directions for using the diagrams are given with each one.

CHAPTER VIII

NOMOGRAPHY

The reader of engineering periodicals is struck by the variety of diagrams used by the authors of the articles therein. Some are simple and others so complicated as to preclude their careful scrutiny. The rectangular coordinate diagram is one of those most employed and often is a mass of squares most of them of no value whatever whereas the alignment diagram based on nomography has no lines on it except the ones marked with the scales.

It is true that a coordinate diagram often has several lines plotted on it referred to different scales on its borders while an alignment diagram represents but one formula and can be used for the solution of but one.

As an example of the simplicity of the alignment diagram over the rectangular diagram take the formula for weight of rails

$W = 17\sqrt[3]{(L + 0.0001LV^2)^2}$
L = greatest load on one driving wheel in tons.
V = maximum velocity, miles per hour.
W = weight of rails, pounds per yard.

The rectilinear diagram is shown in Fig. 161 and requires much interpolation unless the V curves are many which makes the diagram hard to use. Compare this with the alignment diagram for solving the same formula which is shown in Fig. 162. Here three lines are drawn and divided into parts. The values of W for any values of L and U are found by placing a straight edge to connect the L and U assumed values and finding the point where the edge intersects the W line.

The basis of alignment diagrams is the book of Prof. Maurice d'Ocagne "Traite' de Nomographie" published in 1899. This work has been followed by those of other writers among them being the books of Prof. John B. Peddle and Prof. Joseph Lipka. These books cover the subject from a mathematical standpoint and should be read by those who wish to get an extended knowledge of the subject.

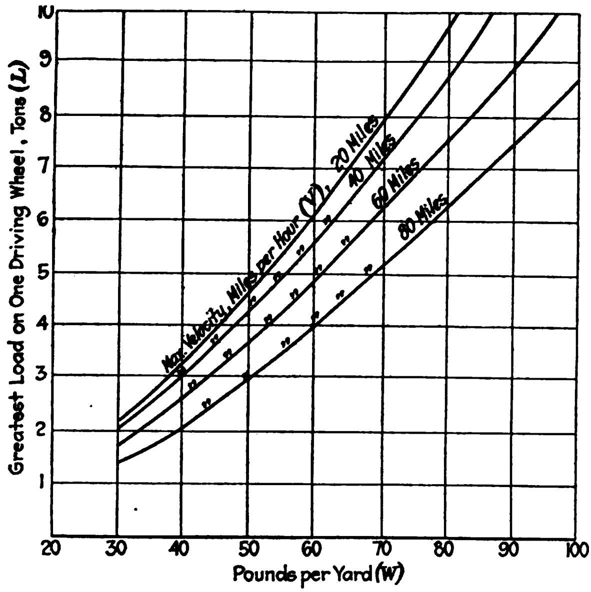


Fig. 161.—Diagram for finding the weight of rails per yard.

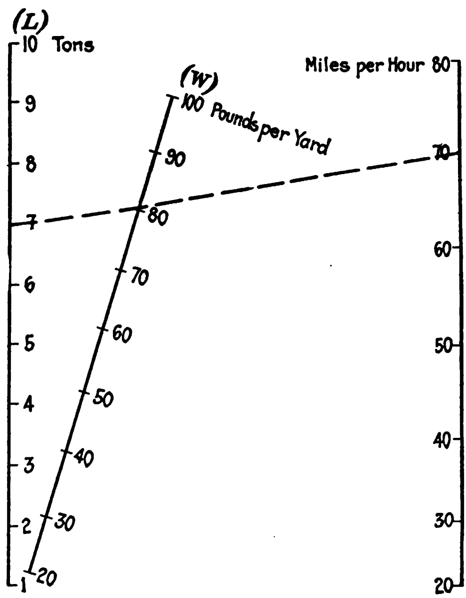


Fig. 162.—Alignment diagram for finding the weight of rails per yard.

A nomograph of a formula is a graph or diagram composed of lines scaled relatively and placed in such relative positions that the values of the variables are found on a line crossing the scales. The object is to substitute for the labor of computation a simple mechanical operation such as the one previously described. It is easy to read a nomogram with precision because of the few lines. It provides a tabulation of all possible values, enables solutions to be made irrespective of what quantity in the formula is unknown and also enables one to observe instantly the effect of a change, either small or great, in any one of the variables. The principles of such diagrams may be given in a general way and simple nomograms be constructed, but equations with many unknown quantities cannot be solved graphically without higher mathematics. There are in general three types of nomograms; A, B and C.

(A) is a nomogram with three parallel rectilinear scales which can be constructed whenever the formula can be written $a + b + c = 0$.

If the formula is in this form already we can use regular ordinary scales, but if it is in the foım $a \times b = c$ it will be necessary to use logarithmic scales as this can then be written $\log a + \log b - \log c = 0$.

(B) This type has two parallel rectilinear scales and one inclined to these two. If the formula is written in the form $a + bc = 0$ this type can be constructed for by taking logarithms this type can generally be converted into type A.

(C) In this type we have two parallel rectilinear scales and one curvilinear scale. This type is constructed when the formula can be written $ac_1 \pm bc_2 \pm c = 0$ where c_1, c_2 and c are functions of the third variable c.

ALIGNMENT DIAGRAMS

Plotting generally is connected in most minds inseparably with two axes at right angles. This is the easiest arrangement when two variables only are concerned. Suppose three to nine variables occur. Then this method fails and vertical axes only can be used to advantage.

Let us take the simplest case, *viz.;* $X + Y = C$ or $U + V = C$ as U- and V-axes are to be vertical (Fig. 163). Draw two verticals AE and BF any convenient distance apart and let AE be the

axis of U and BF the axis of V. Draw the horizontal AB which is the line on which the zeros of the scales of U and V lie. Assume values for C and calculate values of U and V for two cases. Set off along AE these values of U to a scale l_1 units per inch and along BF the values of V to a scale of l_2 units per inch. Let AH represent the value of U corresponding to the value of V represented by BK and AM on U corresponding to BN on V. Join HK and MN. They intersect at G through which a vertical line GC is drawn called the mid-vertical.

AH represents the first value of U called U_1.
BK represents the first value of V called V_1.

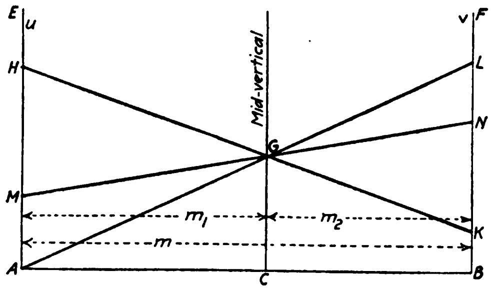


FIG. 163.

Similarly AM and BN represent U_2 and V_2 respectively and since $U + V = C$ we have

$$U_1 + V_1 = C \text{ and } U_2 + V_2 = C \ (A)$$

AH, AM, BK and BN are actual distances on the paper hence $l_1 \times AH = U_1$, $l_1 \times AM = U_2$, $l_2 \times BK = V_1$ and $l_2 \times BN = V_2$. Substituting in

Eq. A above $\qquad (l_1 \times AH) + (l_2 \times BK) = C \qquad (1)$

and $\qquad (l_1 \times AM) + (l_2 \times BN) = C \qquad (2)$

From Fig. 163 $AH = AM + MH \qquad (3)$

$$BK = BN - NK \qquad (4)$$

Multiply (3) by l_1 and (4) by l_2 gives

$$l_1AH = (AM \times l_1) + (MH \times l_1) \qquad (5)$$

$$l_2BK = (BN \times l_2) - (NK \times l_2) \qquad (6)$$

By similar triangles $\dfrac{MH}{NK} = \dfrac{AC}{CB}$ or $NK = \dfrac{MH \times CB}{AC} \qquad (7)$

Add Eqs. (5) and (6) and substitute for NK its value found in (7).

We then have $(AH \times l_1) + (BK \times l_2) = (AM \times l_1) + (MH \times l_1) + (BN \times l_2) - \left(\frac{MH \times CB}{AC} \times l_2\right)$. Substitute from (1) and (2) we have $C = C + MH\left(l_1 - \frac{CB}{AC} \times l_2\right)$. Hence $MH\left(l_1 - \frac{CB}{AC} \times l_2\right)$ must equal zero, which means that $MH = 0$ or $l_1 - \frac{CB}{AC} \times l_2 = 0$. Accordingly, as MH is not zero, $l_1 = \frac{CB}{AC} l_2$ (8). If the lengths AB, AC and BC are represented by mm_1 and m_2 respectively the Eq. 8 becomes $l_1 = \frac{m_2}{m_1} l_2$.

Also $$l_1 + l_2 = \frac{m_2 l_2}{m_1} + l_2 = \frac{(m_2 + m_1)}{m_1} l_2 = \frac{m l_2}{m_1}$$

Whence $$\frac{m_1}{m} = \frac{l_2}{l_1 + l_2} \text{ and } \frac{m_2}{m} = \frac{l_1}{l_1 + l_2}$$

As the values of U and V were any values whatever and the constant C remains the same, the ratio $\frac{m_1}{m_2}$ will always hold and there can only be one mid-vertical. Also G will be a fixed spot vertically over C and any one cross line satisfying the equation $U + V = C$ will locate it on the mid-vertical. GC is then fixed. Let it represent the constant C to some scale say l_3 units per inch. $GC \times l_3 = C$. Substituting in (1) and (2) gives

$$(l_1 \times AH) + (l_2 \times BK) = l_3 \times GC$$
$$(l_1 \times AM) + (l_2 \times BN) = l_3 \times GC$$

Calculate the value of V when $U = 0$ and plot BL to represent this value. Join AL which will pass through G.

When $U = 0$, $V = C$ and BL actually represents C or $BL \times l_2 = C$ but $GC \times l_3$ also $= C$. $\therefore$ $BL \times l_2 = GC \times l_3$. By similar triangles $= \frac{AC}{AB} \times BL \times l_3 = \frac{m_1}{m} \times BL \times l_3$ or $l_2 = \frac{m_1}{m} \times l_3$.

Now $\frac{m_1}{m} = \frac{l_2}{l_1 + l_2}$ $\therefore l_2 = \frac{l_2}{l_1 + l_2} \times l_3$ or $l_3 = l_1 + l_2$ that is the mid-vertical scale is the sum of the scales along the outside axes. Let us take the general case when the equation is $au + bv = c$. Use the same diagram as shown in Fig. 163. The scales must be changed, that of U being opened out a times and that of V opened b times. BL which represented C now represents $\frac{c}{b}$ since it shows the value of V when $U =$ zero.

If l'_1 and l'_2 are the new scales along AE and BF, $l'_1 = \frac{l_1}{a}$ and $l'_2 = \frac{l_2}{b}$

hence the scale along $GC = l_1 + l_2$

$= al_1' + bl_2'$

and $\frac{m_1}{m_2} = \frac{l_2}{l_1} = \frac{bl'_2}{al'_1}$. l'_1 and l'_2 would be the actual scales used.

For a general statement we can regard these as l_1 and l_2 and the GC scale l_3. $l_3 = al_1 + bl_2$ or $\frac{m_1}{m_2} = \frac{bl_2}{al_1}$ where l_1, l_2 and l_3 are the actual scales used.

Summarizing.—If $au + bv = c$ is the general equation. The scale along the midvertical = a times the scale of u + "b" times the scale of V and the division of AB at C is such that $\frac{CB}{AC} = \frac{a \text{ times the "}U\text{" scale}}{b \text{ times the "}V\text{" scale}}$

Most of the formulas found in practice contain products, and often powers and roots besides. By taking logs the multiplications are converted to additions which enables the methods above described to be applied with modifications.

Taking a simple case of horsepower supplied to an electric motor: amperes vary from 2 to 12, volts from 110–240.

$$\frac{\text{watts}}{746} = \text{amperes} \times \text{volts or } 746H = AV$$

Taking logs throughout gives $\log 746 + \log H = \log A + \log V$.

Let $\log 746 + \log H = C$. $A = \log A$ and $V = \log V$. Then the equation becomes $A + V = C$ as in the simple equation $U + V = C$. We can use $l_3 = l_1 + l_2$ and $\frac{n_2}{n_1} = \frac{al_1}{bl_2} = \frac{l_1}{l_2}$.

Instead of actual scales we must now use log scales along the vertical axes. Slide rule scales are convenient for small diagrams. If the "B" scale is used, 9.86 in. would represent two units while 9.86 in. on the C scale would represent one unit. Questions involving more complicated formulas can be dealt with by a combination of charts. When three axes are employed, three variables may be correlated or one axis for each variable. Whatever number of variables occur they may be connected together in threes by merely extending the graphical work of three axes. The plotting of these diagrams can be done as follows:

Settle the range it is desired to indicate on each scale, draw two parallel lines about six inches apart and mark on them a few points of the scale suggested. Do this by using log paper where a log scale is to be used or an ordinary scale in the case of a regular scale. Assume values of the variables scaled on the outer lines and obtain by calculation a value for the third variable. With this value and a second value for the first variable obtain a second value of the second variable. To fulfill the conditions of the diagram these values lie on two straight lines joining points on the two outer parallel lines and crossing at the common value on the central line. One point on the central line determines it.

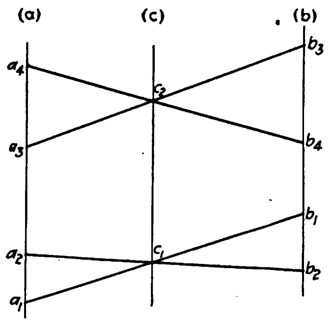


FIG. 164.

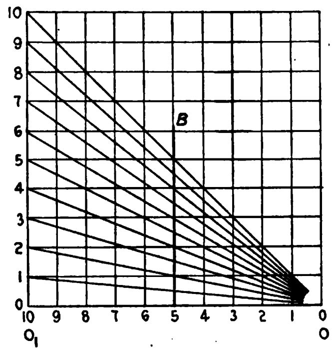


FIG. 165.

Repeat this process at the other end of the diagram and the result will be that two points will be determined giving the position and scale of the central line. Figure 164 shows the three lines, (a) for first variable, (b) for second, both outer scales. As a rule it is necessary to use log scales. To facilitate laying out these scales a scale with modulus 10 should be laid off with a slide rule on paper. Figure 165 line $O_1 10$ will represent such a scale. To find the scale corresponding to any other modulus, take any point O to the right of O_1 and divide OO_1 into equal parts. Find the point on this line corresponding to the required modulus and erect a perpendicular, say $5B$. Join O with each of the scale divisions on $O_1 10$. The points where these lines cut $5B$ will be the points of division of the new scale required.

The term *modulus* is used to designate the length on a scale proportional to a unit difference of logarithms. For example, a scale has a modulus of 2 in. because the distance on the scale

from the point representing 1 to the point representing 10 is 2 in. The log of 1 = 0.000 and that of 10 = 1.000, the difference between them being unity.

When the moduli of the outer scales are not equal the modulus of the middle scale is determined by the following formula in which M_3 = modulus of middle scale, M_1 = modulus of right scale and M_2 = modulus of left scale

$$M_3 = (M_1M_2)(M_1 + M_2) \quad \text{(See Fig. 166)}$$

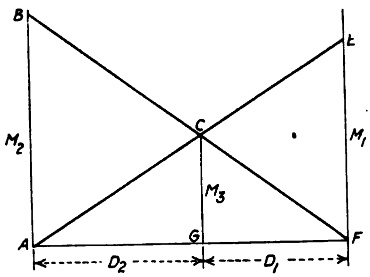


FIG. 166.

At the same time the middle scale must be shifted towards that outer scale which has the smaller modulus. The position of the middle scale is determined by the following equation in which M_1 and M_2 have the same values as before. D_1 = distance from middle to right and D_2 = distance from middle to left.

$$\frac{D_1}{D_2} = \frac{M_1}{M_2}$$

The length of any scale may be determined by the following formula: $L = M\ (\log F_1 - \log F_2)$ where L = length of scale, M = its modulus and F_1 and F_2 = maximum and minimum values of the variable to be represented on the scale.

NOMOGRAMS

Professor Lipka has classified nomograms and formulas in such a way as to enable the engineer to determine to what class of nomogram the formulas belong. This classification is presented here in condensed form and with explanatory notes to assist the delineator or diagram constructor in deciding how he shall construct the nomogram after rewriting the equation in proper form for plotting. A key is given for the kind of diagrams

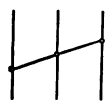
to be used for equations of given form. The fifteen examples given at the end of the chapter have been worked out and diagrams drawn in Prof. Lipka's book.

At the end of the examples a list of nomograms is given, the formula from which they were constructed and where the nomogram can be found. This may prove of assistance to those who wish to construct and use nomograms although the list is not at all complete.

NOMOGRAM FORMULAS

Class Formula Type of diagram

I. $F_1(U) + F_2(V) = F_3(W)$ or Three parallel scales.
$F_1(U) \cdot F_2(V) = F_3(W)$ (This can be brought to first by taking logs of both sides.)



Samples. $U \cdot V = W$ or $\log U + \log V = \log W$

$\sqrt[5]{U \cdot V^4} = W$ or $\log U + 4 \log V = 5 \log W$

$PV^{1.41} = C$ or $\log P + 1.41 \log V = \log C$

$V = 0.785D^2H$ or $2 \log D + \log H = \log V - \log 0.785$

$V = 0.524D^3$ or $\log D + 2 \log D = \log V - \log 0.524$

$Q = 6.3D^2\sqrt{H}$ or $2 \log D + \frac{1}{2} \log H = \log Q - \log 6.3$

$W = 0.0165AP_1^{0.97}$
$W = 0.01296D^2P_1^{0.97}$ or $2 \log D + 0.97 \log P_1 = \log W - \log 0.01296$

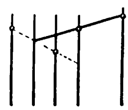
$\dfrac{T_2}{T_1} = e^{-0.01745Fa}$ $\text{Log } T_2 - \log T_1 = -0.01745Fa \log e$

$HP = \dfrac{(T_1 - T_2)S}{33{,}000}$ $\text{Log }(T_1 - T_2) + \log S = \log HP + \log 33{,}000$

II. $F_1(U) + F_2(V) + F_3(W) + \ldots = F_4(t)$
or $F_1(U) \cdot F_2(V) \cdot F_3(W) \ldots = F_4(t)$ } four or more parallel scales

Extension of I and same method used.

Samples. $v = c\sqrt{rs}$ or $\frac{1}{2} \log s + \frac{1}{2} \log r + \log c = \log v$. Introduce $q = \frac{1}{2} \log s + \frac{1}{2} \log r$ and $q + \log c = \log v$ and construct diagram for each equation.



$V = CR^{0.63}S^{0.54}(0.001)^{-0.04}$. Replace $(0.01)^{-0.04}$ by 1.318 and expressing R in inches.

$V = 0.2755CR^{0.63}S^{0.54}$ or

$0.63 \log R + 0.54 \log S + \log C + \log 0.2755 = \log V$ which is of form II.

$$HP = \frac{PLAN}{33{,}000} = \frac{\pi PLD^2N}{(33{,}000)(4)(12)} = 0.000001983PLD^2N$$

This is charted in three parts: (1) $PL = q$; (2) $D^2N = t$; (3) $HP = 0.000001983\ qt$.

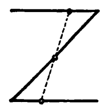
$PL = q$ is written $\log P + \log L = \log q$ (form I). $D^2N = t$ is written $2 \log D + \log N = \log t$ (form I) and (3) is written $\log q + \log t = (\log HP - \log 0.000001983)$ (form I).

III. $F_1(u) = F_2(v) \cdot F_3(w)$ or $F_1(u) = F_2(v)^{F_3(W)}$ Z chart.

Second form brought to first by taking logs. First form same as second form of class I but using three natural scales two parallel and one oblique instead of three parallel log scales.

$D = 1.24\sqrt{\dfrac{L}{F_t}} + 0.088.$ Write in form

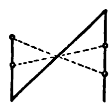
$L = F_t\dfrac{(D - 0.088)^2}{(1.24)^2}$ (form III)



IV. $\dfrac{F_1(u)}{F_2(v)} = \dfrac{F_3(w)}{F_4(q)}$. Two intersecting index lines.

This is included in second form of II but there log scales, here natural scales.

$$HP = \frac{2\pi LNW}{33{,}000} \quad \text{or} \quad \frac{HP}{N} = \frac{W}{5{,}260/L}$$

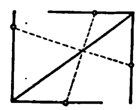


(a)

$$\Delta = \frac{WL^3 1{,}728}{192EI} \quad \text{or} \quad \frac{\Delta}{L^3} = \frac{W}{3{,}333{,}000I}$$

$$\Delta = \frac{WL^3 1{,}728}{192aEI} \quad \text{or} \quad \frac{\Delta}{L^3} = \frac{W}{3{,}333{,}000aI}$$

$$N_s = \frac{N\sqrt{HP}}{H^{5/4}} \quad \text{or} \quad \frac{N_s}{N} = \frac{\sqrt{HP}}{H^{5/4}}$$

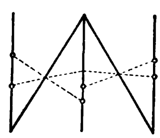


(b)

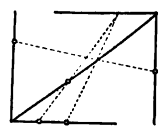
V. $F_1(u) = F_2(v) \cdot F_3(w) \cdot F_4(t)$. Two or more intersecting index lines.

Similar to second form of II but use natural scales in place of log scales.

$$M = 0.196FD^3 \text{ or}$$
$$M : D^3 = F : 5.1$$
$$P = \frac{B^2L}{C^2wd^5}$$



(a)



(b)

$$F = \frac{9WL}{BH^2} \qquad 2 \text{ eq.} \frac{F}{L} = \frac{W}{Q} \text{ and } \frac{Q}{B} = \frac{H^2}{9}$$

$$\Delta = \frac{1{,}728WL^3}{192EIP} \quad 2 \text{ eq.} \frac{Q}{L^3} = \frac{W}{3{,}333{,}000I} \text{ and } Q = \Delta P$$

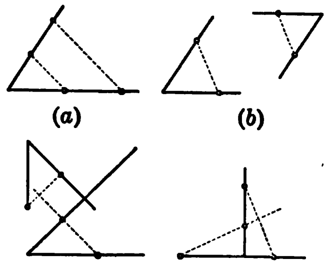
VI. $F_1(u) : F_2(v) = F_3(w) : F_4(q)$
Parallel or perpendicular index lines.

$$W = \frac{\pi d^2 v}{576\ V} \text{ or}$$

$$W : d^2 = v : 183.5V$$

$$\frac{R_1}{R_2} = \frac{234.5 + t_1}{234.5 + t_2}$$

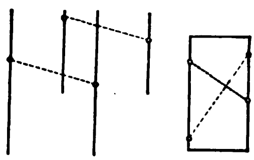
$$\frac{D^2}{d^2} = \frac{F + P}{F - P}$$



(a) (b) (c) (d)

VII. $F_1(u) - F_2(v) = F_3(w) - F_4(q)$ or $F_1(u) : F_2(v) = F_3(w) : F_4(q)$ Parallel or perpendicular index lines.

Second form can be transferred to first by taking logs of both sides. Second form same as VI only we here use log scales.



(a) (b)

$$H = \frac{Flv^2}{2dg} \text{ or } \frac{268.33H}{l} = \frac{v^2}{d} \text{ and}$$

$$(\log H + \log 268.33) - \log l = 2 \log v - \log d$$

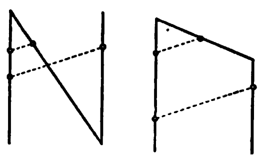
VIII. $F_1(u) + F_2(v) = \dfrac{F_3(w)}{F_4(q)}$. Parallell or perpendicular index lines.

$$I = \frac{W}{12}(3r^2 + h^2) \text{ or}$$

$$3r^2 + h^2 = 12I : W$$

$$R = (p - D)tF_t \text{ or}$$

$$p - D = \frac{R/55{,}000}{t}$$

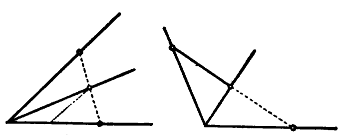


(a) (b)

IX. $\dfrac{1}{F_1(u)} + \dfrac{1}{F_2(v)} = \dfrac{1}{F_3(w)}$ or

Three or more concurrent scales.

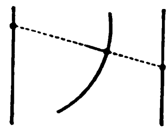
$$\frac{1}{F_1(u)} + \frac{1}{F_2(v)} + \frac{1}{F_3(w)} + \cdots\cdots = \frac{1}{F_4(q)}$$



(a) (b)

X. $F_1(u) + F_2(v) \cdot F_3(w) = F_4(w)$

Straight and curved scales.



$q + Nq^{5/6} = P$ or

$P - Nq^{5/6} = q$

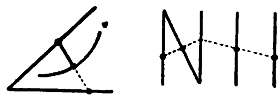
$Q = 3.33(B - 0.2H)H^{3/2}$

$w^3 + pw + q = 0$

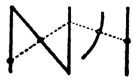
$w^2 + pw + q = 0$

$w^3 = nw^2 + pw + q = 0$

XI. Additional forms; combined methods.

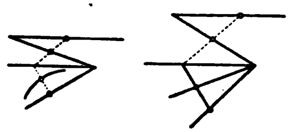


(a) $\dfrac{1}{F_1(u)} + \dfrac{F_4(w)}{F_2(v)} = \dfrac{1}{F_3(w)}$



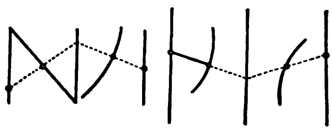
(b) $F_1(u) + F_2(v) \cdot F_3(w) = F_4(q)$

(c) $F_1(u) \cdot F_4(q) + F_2(v) \cdot F_3(w) = 1$



(d) $\dfrac{F_4(q)}{F_1(u)} + \dfrac{1}{F_2(v)} = \dfrac{1}{F_3(w)}$

(e) $\dfrac{F_4(q)}{F_1(u)} + \dfrac{F_3(w)}{F_2(v)} = 1$



(f) $F_1(u) \cdot F_2(q) + F_3(v) \cdot F_4(w)$
$= F_5(w)$

(g) $F_1(u) \cdot F_2(q) + F_3(v) \cdot F_4(w)$
$= F_5(q) + F_6(w)$.

Nomogram Examples

1. $\sqrt[5]{u \cdot V^4} = W$ in McMath run off formula.

   $m_1 = 10$ $\quad m_2 = \dfrac{10}{4}$ $\quad m_3 = 2$ $\quad m_1 : m_2 = 4:1$

2. $V = 0.524D^3$ Volume of a sphere.

   $m_1 = 10$ $\quad m_2 = 5$ $\quad m_3 =$ $\quad m_1 : m_2 = 2:1$

3. HP $= \dfrac{(T_1 - T_2)S}{33{,}000}$ = Horsepower of belting

   $m_1 = 5$ $\quad m_2 = 5$ $\quad m_3 =$ $\quad m_1 : m_2 = 1 : 1$

4. $V = C\sqrt{rs}$ Chezy formula for velocity of flow of water in open channels

   $m_1 = 10$ $\quad m_2 = 10$ $\quad m_3 =$ $\quad m_4 = 5$ $\quad m_5 =$

5. HP. $= 0.000001983\ PLD^2N$ indicated horsepower of steam engine.

   $m_1 = 10$ $\quad m_2 = 10$ $\quad m_3 =$ $\quad m_1 : m_2 = 1 : 1$

   $m_4 = 5$ $\quad m_5 = 10$ $\quad m_6 =$ $\quad m_4 : m_5 = 1 : 2$

   $m_3 : m_6 = 5 : 3.33$

6. $L = F_t \dfrac{(D - 0.088)^2}{(1.24)^2}$ Tension on bolts with U. S. standard threads.

$m_1 = 0.0001 \qquad m_2 = 0.0001$

7. HP. $= \dfrac{2\pi LNW}{33,000}$ = Prony brake or electric dynamometer.

Scale	Limits	Modulus
HP	0 – 80	$m^1 = 0.15$
N	0 – 5,000	$m_2 = 0.00225$
W	0 – 400	$m_3 = 0.03$
L	0.5 – 5	$m_4 = 0.00045$

8. $M = 0.196\ FD^3$ = Twisting moment in a cylindrical shaft.

Scale	Limits	Modulus
M	Up to 190,000	$m_1 = 0.00005$
D	1 in. to 4 in.	$m_2 = 0.1$
F	Up to 16,000	$m_3 = 0.0005$

9. $F = \dfrac{9WL}{BH^2}.$ Distributed load on a wooden beam.

First equation $\dfrac{F}{L} = \dfrac{W}{Q}.$ Second $\dfrac{Q}{B} = \dfrac{H^2}{9}$

Scale	Limits	Modulus
F	Up to 2,000	$m_1 = 0.003$
L	Up to 40	$m_2 = 0.3$
W	Up to 15,000	$m_3 = 0.0008$
Q		$m_4 = \dfrac{m_2 m_3}{m_1} = 0.08$
Second equation		
Q		$m_5 = 0.08$
B	Up to 10	$m_6 = 1$
H	Up to 12	$m_7 = 0.08$
		$m_8 = 1$

10. $W = \dfrac{\pi d^2 v}{576V}$ Weight of gas flowing through an orifice.

Scale	Limits	Modulus
W	0 to 0.4	$m_1 = 10$
d	0.2 to 2	$m_2 = 1$
v	0 to 3,000	$m_3 = 0.00135$
V	0 to 200	$m_4 = 0.000135$

11. $\dfrac{D^2}{d^2} = \dfrac{F + P}{F - P}$ Lamé formula for thick hollow cylinders subjected to internal pressure.

Scale	Limits	Modulus
d	2 to 16	$m_1 = 0.03$
D	2 to 20	$m_2 = 0.02$
$F - P$	0 to 10,000	$m_3 = 0.00075$
$F + P$	0 to 20,000	$m_4 = 0.0005$

12. $H = \frac{Flv^2}{2dg}$ Friction loss in flow of water.

Scale	Limits	Modulus
H	0.5 to 20	$m_1 = 5$
l	20 to 1,000	$m_1 = 5$
v	2 to 10	$m_1 = 5$
d	1 to 24	$m_1 = 5$

13. $I = \frac{W}{12}(3r^2 + h^2)$ Moment of inertia of cylinder.

Scale	Limits	Modulus
r	0 to 25	$m_1 = 0.008$
h	0 to 40	$m_1 = 0.008$
I	0 to 6,000,000	$m_3 = 0.000,0002$
W	0 to 25,000	$m_4 = 0.000,375$

14. $Q = 3.33(B - 0.2H)H^{3/2}$ Francis formula for a contracted weir.

B varies	0 to 5	$m_1 = 0.3$
H varies	0 to 8	$m_2 = 0.6$
Q varies	0 to 33	$K = 12$

15. $K = \frac{1}{2}bc \sin A$. Area of triangle K with sides b(0 to 10) and c (1 to 10) and included angle A (0° to 90°).

NOMOGRAMS

Formula	What it is for	Author, nomogram shown
$R = \frac{3.34V^2}{D}$		Hezlet book
$d = \sqrt[3]{\left(\frac{C}{K}\right)^2}$		Hezlet book
$Q = 95(H + 0.7)^{3/2}$	Weir (metric units)	Strachan *Trans.* A.S.C.E., February, 1915
$V = \frac{\pi h}{12}(D^2 + Dd + d^2)$	Volume conical frustum	Strachan *Trans.* A.S.C.E., February, 1915
$V = q\frac{a^{0.75}}{p^{0.5}}t^{0.7}$	Speed of perforation of projectile	Strachan *Trans.* A.S.C.E., February, 1915
$P = \frac{s}{1 + \frac{l^2}{nr^2}}$	Gordon formula for columns (metric units)	Strachan *Trans.* A.S.C.E., February, 1915

$m = \sqrt{\frac{R+P}{R-P}} - 1$	Thickness of hollow cylinders	Strachan *Trans.* A.S.C.E., February, 1915
$N = 18{,}293(1 + 0.002837 \cos 2\lambda) \left[1 + \frac{2(T+t)}{1{,}000}\right] \log \frac{H}{h}$	Barometric formula for determining heights.	Strachan *Trans.* A.S.C.E., February, 1915
$f = \frac{5pl^4}{384EI}$	deflection of uniformly loaded beam	De Mussan
$\frac{Pl^2}{8} = R\frac{I}{V},\ P = 13{,}000\frac{D^{2.6}e}{L^{1.7}}$	Hollow cast-iron columns (Hodgkinson's)	De Mussan
$P = \frac{S\pi d^3}{16R}$ and $f = \frac{64PRn}{Gd^4}$	Reuleaux formula for springs	De Mussan
$P = \frac{2\pi^2 EI}{L^2}$(third case); $P = \frac{4\pi^2 EI}{L^2}$(fourth case)	Euler's formulas	De Mussan
Moment of inertia and resistance of four angles equal legs		De Mussan
Weight and moments of four angles unequal legs		De Mussan
Weight per linear meter of steel bars and plates		De Mussan
$M = 0.098FD^3 = F\frac{DA}{8}$	Pin moments	Strachan
$P = \dfrac{20{,}000}{1 + \frac{l^2}{8{,}000\,r^2}}$	Gordon columns	Strachan
$S = 125 - \frac{1}{8}\sqrt{2{,}000\,L - L^2}$	Impact for bridges	Strachan
	Public Service Commission First District of New York	
Concrete (reinforced) beam formulas		Strachan
$V = Cr^{0.63}s^{0.54}(0.001)^{-0.04}$	Williams-Hazen	Strachan
$U = \frac{6L + md}{mp}$ and $n = \sqrt{Ku}$	Rivets supporting an eccentric load	(Eliot)
	Stresses in Fink Truss.	Trans. A.S. C.E. Eliot
Reinforced-concrete beams (resistance moment equal); Reinforced-concrete beams (resistance moment unequal)		(Eliot)

Rectangular beams (yellow pine) (Eliot)

$p = \frac{Rh}{V}$ Flange rivets in plate girder (Eliot)

$\Delta = \frac{5WL^3}{384EI}$ Deflection of steel beams (Eliot)

$q + N_q^{1/4} = P$ Buerger run-off (Eliot)

$D = (100[(p + R)^2 + q^2]^{1/2}) - 100$ Drop in alternating-current wiring, single phase, Two-phase, four-wire low-potential systems (Eliot)

Ernest W. Tipple (Line Charts)

$2x + 3y = C$	General formula.
$P = 35{,}500D^{0.7} \times T^{0.6}$	Thrust on drills.
$C = BY - AX$ or $C = \frac{Y^b}{x^a}$	Subtraction or division.
$D = 52\left(\frac{H^{0.2}}{R^{0.6}}\right)$ and $D = 48.5\left(\frac{H^{0.2}}{R^{0.6}}\right)$	For finding ideal diameter of screw propellers (three variables).
$P = \frac{72{,}000T^2}{R^2}$	Strength of unstayed flat circular plates (three variables).
$HP = 0.0607D^2\left(\frac{U}{100}\right)^3 \times \frac{1}{V}$	Frictional horsepower loss at disc rotating in steam (four variables).
$HP = 0.458D\left(\frac{U}{100}\right)^3 \times \frac{L^{1.5}}{V}$	Frictional horsepower loss at vanes of turbines (five variables).
$F = \frac{SN^2L^2D}{28{,}000K^2}$ and $\frac{SN^2L^2D}{54{,}667K^2}$	Bending stresses in locomotive coupling and connecting rods (six variables).

Inst. Aut. Engr's., 1917–18 (Transactions)

$x = a^n$	Powers and roots of numbers.
$V = at$	Velocity, acceleration and time.
$V^2 = 2aS$	Velocity, acceleration and space.
$S = \frac{at^2}{2}$	Acceleration, time and space.
$F = \frac{Wa}{g}$	Force, weight and acceleration.
$KE = \frac{Wv^2}{2g}$	Kinetic energy.

$CF = 0.000343WrN^2$	Centrifugal force.
$\left(\frac{V_2}{V_1}\right)^n = R^n = \frac{P_2}{P_1}$	Compression ratio and pressure.
$T_m = f\frac{\pi}{16}D^3$	Twisting moment of solid shafts.
$R = \sqrt[3]{\frac{r^2 - b^2}{r}}$	Hollow and solid shafts compared.
$T_m = \frac{63{,}025HP}{N}$	Twisting moment from horsepower.
$W = \frac{Y}{D}$, $E = YD^2$, $L = MP$	Helical spring diagram.
$V_c = \frac{\pi}{4}D^2S$, $Q = V_cJ$	Cylinder and working volume.
$HP = \frac{P_mQN}{396{,}000}$	Horsepower from mean effective pressure.
$V_g = \frac{QN}{180\pi D_1^2}$	Pipe sizes for engines.
$V_g = \frac{V_cN}{360\Delta}$	Valve area.

John B. Peddle (Graphical Charts)

$A = \frac{WL}{144}$	Chart for areas.
$P = 50{,}210{,}000\left(\frac{t}{D}\right)^3$	Stewart's formula for collapsing pressures of Bessemer-steel tubing.
$M = 0.196D^3F$	Chart for twisting moment in cylindrical shafts.
$S = Vt + g\frac{t^2}{2}$	Space passed over by falling body.
$P = 0.196\frac{d^3}{r}f$	Load supported by helical spring.
$W = 1{,}600bh^2$	Load on rectangular beams.

Proportional Charts

$\frac{D}{d} = \sqrt{\frac{f + p}{f - p}}$	Lamé formula for strength of thick hollow cylinders subject to internal pressure.

$\frac{P}{h} = \frac{W}{\left(\frac{1 - \sin\phi}{1 + \sin\phi}\right)^2}$	Resistance of earth to compression.
$\frac{C}{w} = \frac{r^2}{gr}$	Centrifugal force (C).
$d = 0.013\sqrt{Dlp}$ or $\frac{d^2}{D} = \frac{l}{\frac{5.917}{p}}$	Piston rod diameter.
$I = \frac{W}{12}(B^2 + L^2)$	Polar moment of inertia of a flat rectangular plate.
$F = h\left(\frac{7.64}{T_2} - \frac{7.95}{T_1}\right)$	Intensity of chimney draft.
$P = \frac{5}{1 + \frac{L^2}{800D^2}}$	Safe load on hollow round cast-iron columns with flat ends.
$Q = 3.33(L - 0.2H)H^{3/2}$	Francis' Weir Formula.
$V = \frac{2}{3}\sqrt{2g}\,\frac{H_1^{3/2} - H_2^{3/2}}{H_1 - H_2}$	Flow of water through rectangular orifices.
$M = \frac{f^2}{2E}$	Modulus of resistance.
$E = \frac{W}{2g}(V_1^2 - V_2^2)$	Energy of a moving mass.
$V = \frac{158\sqrt{RS}}{1 + \frac{N}{\sqrt{R}}}$	Bazin formula for flow of water in open channels.
$T = \frac{P10^{0.0076Fa}}{10^{0.0076Fa} -}$	Chart for brake bands.

Joseph Lipka Graphical & Mech. Computation

$U \times V = W$	Multiplication chart.
$U \times V = W$ $\sqrt[5]{UV^2} = W$ $PV^{1.41} = C$ $V = 0.785D^2H$ $V = 0.524D^3H$ $Q = 6.3D^2\sqrt{H}$	Combination chart.
$W = 0.0165AP^{0.97}$	Grashof's formula.

W. N. Rose (Math. for Engineers)

$t = 0.7d + .005D$ Thickness of edge of pulley rim. (d ranges from 0.1 to. 5 in. and D from 3 to 10 in.).

$Q = \frac{62.4}{144} \times \frac{\pi}{4} d^2v = 0.34d^2v$ Flow of water through circular pipes. (Pipe diameters 1 to 9 in. velocity of flow 1 to 10 ft. per second.)

$T = \frac{791H}{Np^3}$ Number of teeth necessary for strength in cast-iron gearing.

$t = 0.7\,d + 0.005\,D$ Thickness of edge of pulley rim.

$H = \frac{AV}{746}$ Horsepower in volts and amperes.

$Q = \frac{62.4}{144} \times \frac{\pi}{4} d^2\,V = 0.34d^2V$ Quantity of water flowing through circular pipes.

$T = \frac{791H}{Np_3}$ Number of teeth in cast-iron gearing to transmit horsepower.

Capt. R. K. Hezlet (Nomography)

$C^2 = a^2 + b^2, R = 3.34\frac{V^2}{D}$ (Molesworth, p. 251).

$Q = 4{,}000\,D^2\sqrt{P}$ (Molesworth, p. 483).

$W = 17\sqrt[3]{(L + 0.000ILV^2)^2}$ (Molesworth, p. 223). Weight of rails.

$t = 0.000125Pd + 0.15\sqrt{d}$ Thickness of cast-iron pipes. (Molesworth, p. 311)

$R = \sqrt[3]{\frac{r^4 - b^4}{r}}$ (Molesworth, p. 389) hollow shafts.

$Q = 1{,}350D^{2.5}\sqrt{\frac{0.45L}{H}}$ Discharge of gas in pipes. (Molesworth, p. 360)

$M = PR^n$ compound interest formula.

P = Principal. n = number of years. M = Amount.

$R = 1 + \frac{r}{100}$, R = Amount of 1£ for 1 year at r per cent per annum.

CHAPTER IX

MECHANICAL GRAPHICAL RECORDS

RECORDING INSTRUMENTS

The preceding pages have touched on graphical methods of drawing diagrams but in all cases these diagrams have been drawn by hand using tables on formulas as a basis. Engineers have found that it is very necessary in the keeping of records of many operations, or processes or conditions, to have these records made by graphical recording instruments. These instruments make records which show on paper the occurrences taking place over some period of time. These periods may be from minute to minute, hour to hour or day to day but in nearly all cases the element of time enters in, which necessitates the use of a clock as the driving mechanism either to rotate a circular disc or move a ribbon of paper on which a marking point leaves a record of its movement. This marking point is usually connected to an operating device controlled by the mechanism or condition which is to be recorded. Thus a recording thermometer marks the temperatures on a disc or ribbon moved by a clock. A CO_2 recorder shows the percentage of CO_2 in the flue gas of a boiler from hour to hour by the movement of a pen actuated by a gas analysis apparatus.

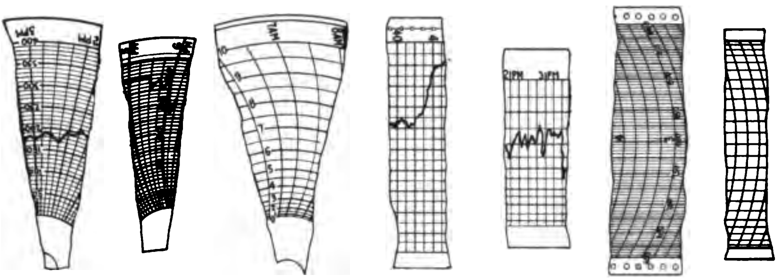
A tensile-testing machine on the other hand does not depend on a clock for moving the paper as the operation of the machine rotates a drum on which the paper is wrapped. The same is true of the paper on a steam-engine indicator and on a recording dynamometer for testing the drawbar pull of a tractor. Such instruments serve an important purpose in making a record which can be inspected at any time, one which can easily be compared to another, besides acting as a check on operations which involve the personal element. It is proposed to show in the following pages graphical records made by recording instruments. Where possible these will be reproductions of actual records made by these instruments themselves.

The first examples and the most common ones are on circular discs. These have various types of ordinates as shown in Fig. 167 *a,b* and*c*.

a has radial ordinates with uniform scale from center to periphery.
b has circular ordinates, uniform scale.
c has circular ordinates, non-uniform scale.

Besides the disc records there are those made on a ribbon or rectangular sheet of paper. These are of the types shown in Fig. 167 *d, e, f,* and *g*.

d has rectangular ordinates of uniform scale
e has rectangular ordinates of non-uniform scale
f has circular ordinates of uniform scale
g has circular ordinates of non-uniform scale



(a) (b) (c) (d) (e) (f) (g)

FIG. 167.

Besides these there are circular time recorders which are not divided to scale radially but have the circumference divided into hours and minutes as in Figs. 170 and 178. There are pressure records whose ordinates must be calibrated according to the various springs or diaphragms used in them. Under this head come the indicator diagrams from steam ~~and oil~~ engines.

In the class denoted by 167*a* will be found the record in Fig. 168 from a Venturi water-meter covering a period of 24 hr. and giving the flow of water to a boiler in pounds per hour.

Figure 169 is a record from a Uehling CO_2 analyzer which shows the variation in CO_2 found by chemical analysis of the gas taken from the flue of a steam boiler. The radial distances represent percentages of CO_2 while the divisions around the circumference are time intervals.

To obtain an average of such a diagram it is necessary to measure the diagram with a polar averaging instrument which is made especially for this work. A record for the same purpose but made in a different way and increasing from periphery inwards, is the polar diagram from the automatic CO_2 combustion

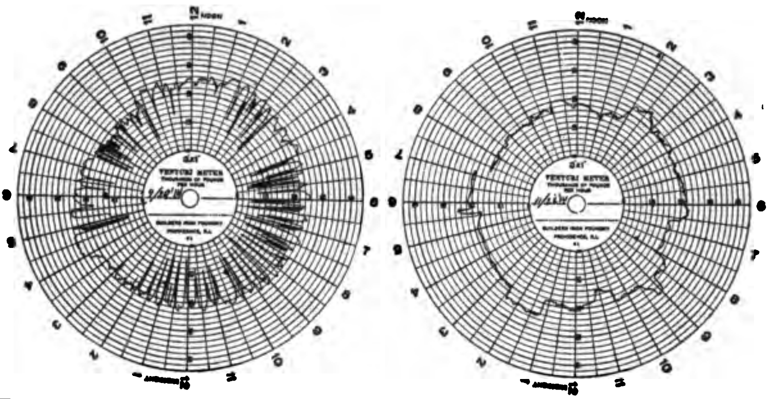


FIG. 168.—Venturi meter records showing improvement in feed water regulation.

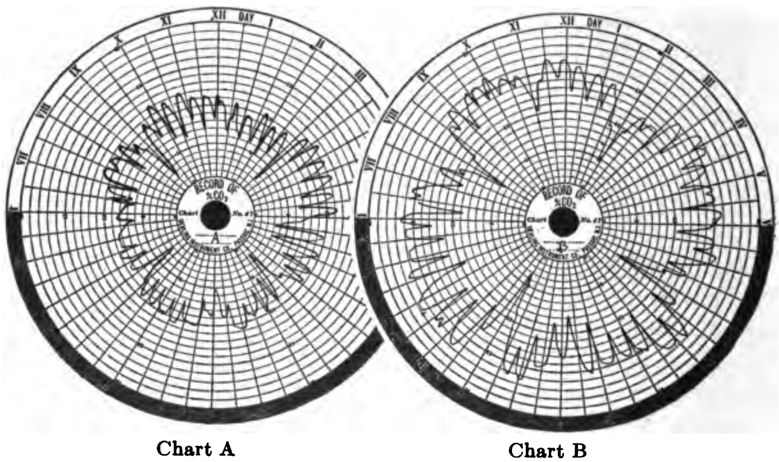


Chart A Chart B

FIG. 169.—Records from Uehling analyser. A shows av. 8.45 per cent CO_2 B shows av. 13.2 per cent CO_2.

recorder of the Precision Instrument Co. shown in Fig. 170. The *blacker* the chart the better the performance of the furnace and fireman.

On the other hand the diagram of the Hays Automatie CO_2 and Draft Recorder increases from center outwards and the *less* of

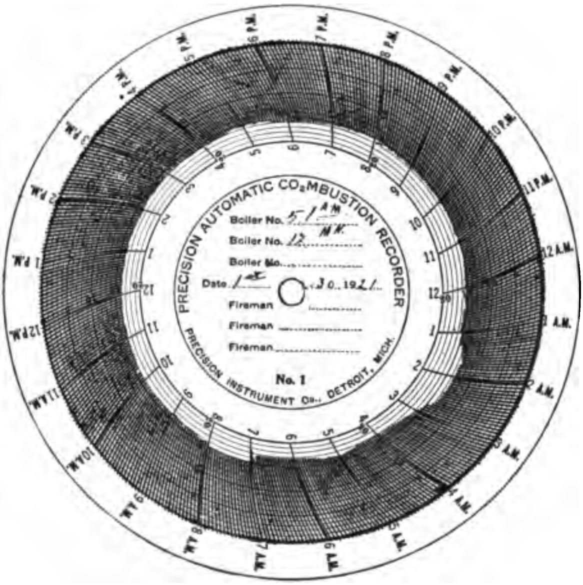


FIG. 170.—Automatic CO_2 recorder chart.

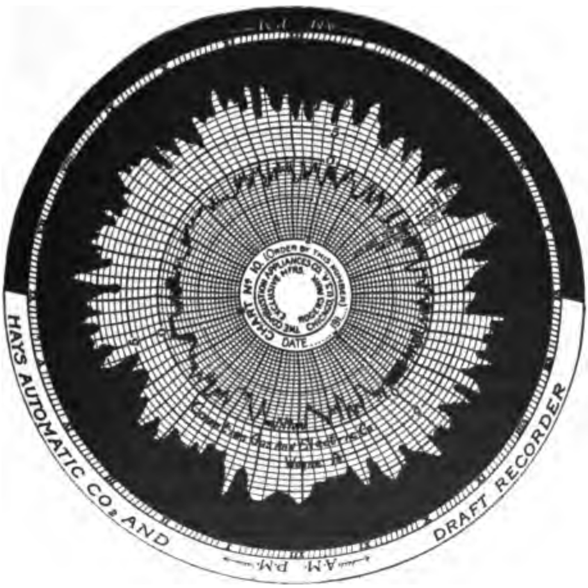


FIG. 171.—Combined draft recorder and CO_2 automatic recorder.

black the better the performance. This diagram, Fig. 171, also has on it another scale with a record nearer the center showing draft in the furnace, the scale increasing towards the center from the zero circle which is half way from center to periphery. By having two record lines on the same chart it is easy to compare the bearing the draft has on CO_2.

In Fig. 172 a diagram from a Brown Instrument Co. recording thermometer is shown. This belongs in the class shown in Fig. 167*b* and has curved ordinates with uniform scale. It is adapted

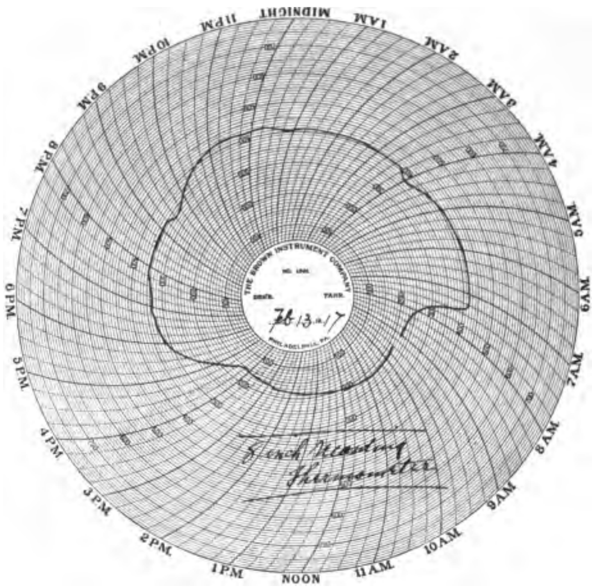


Fig. 172.—Chart from recording thermometer.

to temperatures above 100°F. and makes a 24-hr. record. Another type of multi-recording instrument is the Bailey Boiler Meter which makes the diagram shown in Fig. 173.

The inner portion of the chart contains records of steam temperature in red and flue-gas temperature in blue. Distances between concentric circles represent degrees of temperature according to the scales for the respective curves.

The outer portion of the chart is divided into circles denoting rate of flow of air or steam. The records are in blue for air and red for steam. Comparisons can be easily made between the

four curves when they are located on the same sheet which is rotated by clockwork. These charts are 12 in. in diameter.

We find in type 167c the records made by a G. E. flow meter which records steam flow in pounds per hour, gallons of water per minute or boiler horsepower (using 30 lb. per hour as a unit). This is shown in Fig. 174. The readings increase from the center outwards and the divisions are unequal.

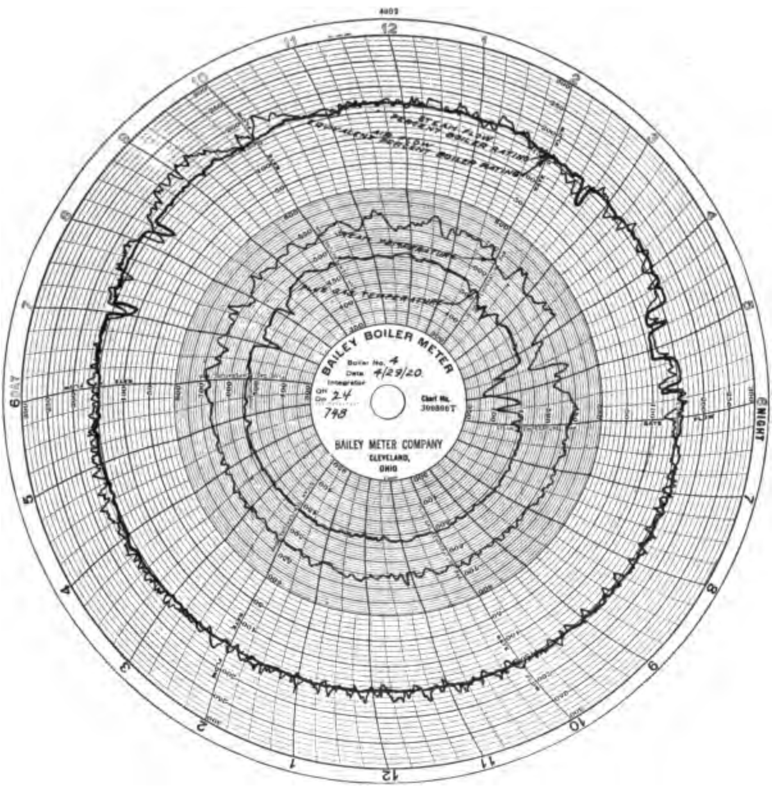


FIG. 173.

A type of chart containing a time record as well as a pressure record is shown in Fig. 175. The outer part of the disc is divided into 10 sections of 6 sec. each by concentric circles over which a pen travels which records the distance travelled. The distance between the ordinates represents 100 ft. The chart is made to rotate by an odometer wheel which rolls on the ground

and transmits motion to the chart by a flexible shaft and gearing. The drawbar pull is shown by the irregular marking between the curved ordinates. The pen marking in the annular space at the margin of the chart indicates the elapsed time. A clock trips the pen at one minute intervals. This dynamometer is used for recording the horsepower delivered at the drawbar by tractors and was devised by the Hyatt Roller Bearing Co. As stated above it gives drawbar pull, time and distance from which the drawbar horsepower can be computed.

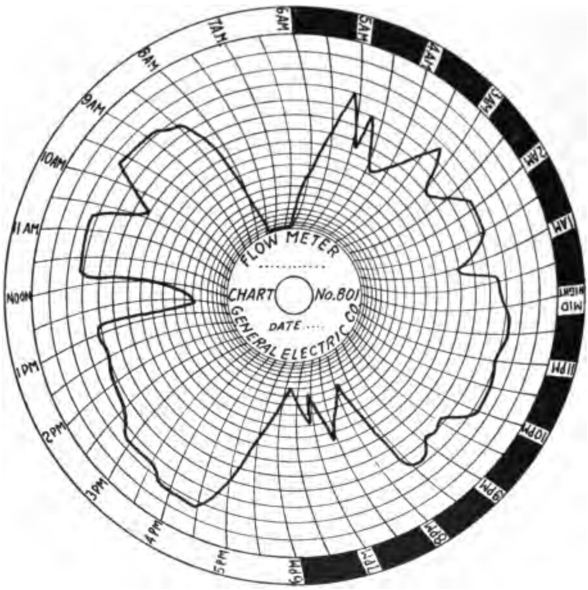


Fig. 174.—Chart from General Electric flow meter.

In Fig. 176 is shown a chart belonging to the time recorder class in which the disc is turned by clockwork, and the record made whenever motion or operation takes place. This chart indicates when a motor truck is in operation by making a broad black mark. The narrow line shows the truck is standing still. The margin is divided into 24 hr. which are subdivided into 10-min. intervals.

A type of chart embracing more records than one is shown by the Bristol Time Recorder in Fig. 179. This type of chart may have from 1 to 12 records on it of operations which may or may

not have any relation to each other. In the chart shown, the outer circle registers feed-water consumption, the next, coal going to stokers, third switch board breaker openings, fourth drop of pressure in hydraulic elevator line and fifth operation of

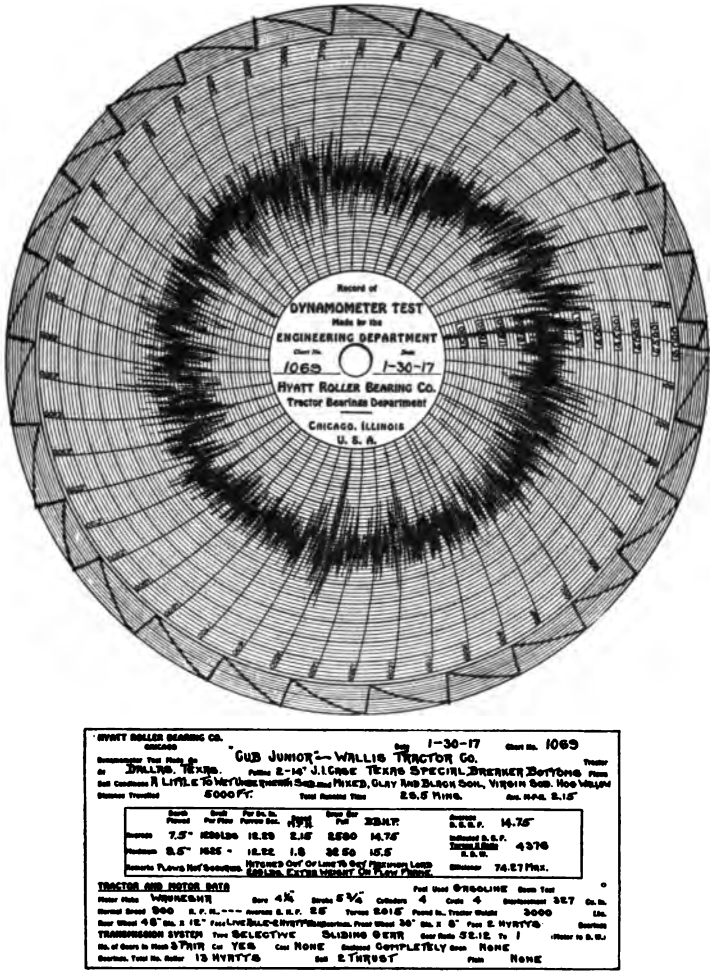


FIG. 175.—Record of dynamometer test on tractor.

an ash conveyor. The instant of operation is shown by the break in the continuous line. The chart is rotated by clockwork and covers a 24-hr. period. Circular recording instruments are limited from the fact that the record usually has to be changed

13

every 24 hr. whereas with the continuous tape the record may run continuously for weeks or months. It can also be made to travel a high speed for short periods thus enabling a better graphic record to be made of rapidly occurring operations.

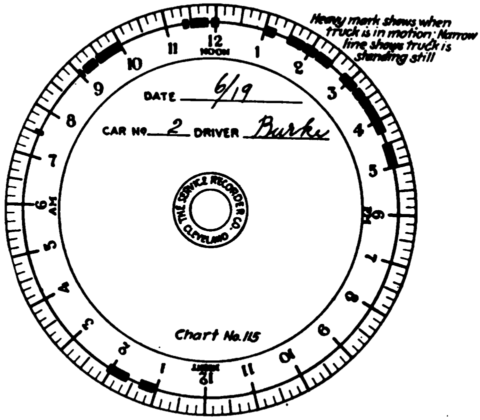


FIG. 176.

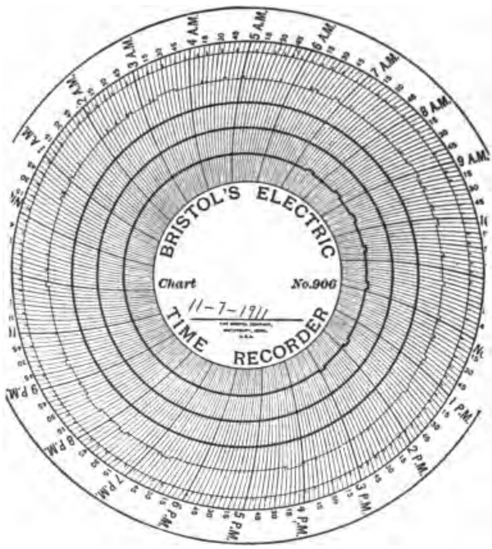


FIG. 177.—Record from Bristol time recorder.

Figure 167*d* record is made by a pen moving on a strip of paper driven along by clockwork. Figure 178 is a record of this type made on a "Recordograf" and shows the movement

and stoppage of a truck. The tape in this case is 36 hrs. long. The squares represent 5 min. each along the tape and $\frac{1}{4}$ mile each across the tape. It can be readily seen that horizontal

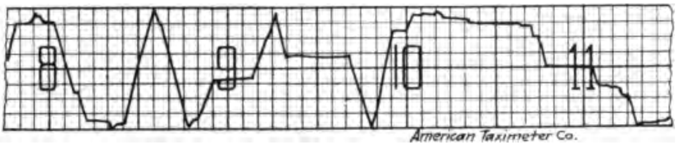


Fig. 178.

lines or abscissas represent stoppages and inclined lines movements, the steeper the line the faster the movement.

In Fig. 179 is shown a graphic record of the electric current used in operating a shear scarfer. The movement of the paper is

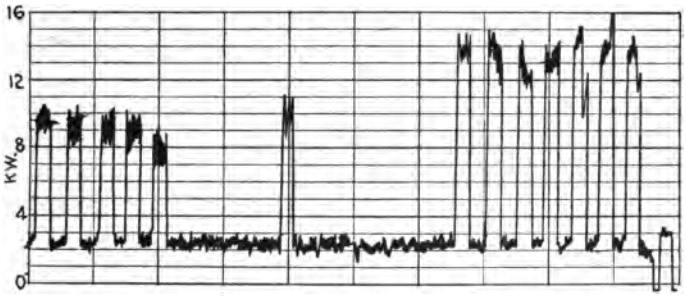


Fig. 179.—Record from shear scarfer.

accomplished by clockwork, the speed in this case being 24 in. per hour. The peak load varies, as shown by the irregular line, from 10 to 13 kw.

A record made by the pulsations of the human heart is called a cardiograph. Such a record is shown in Fig. 180. This is

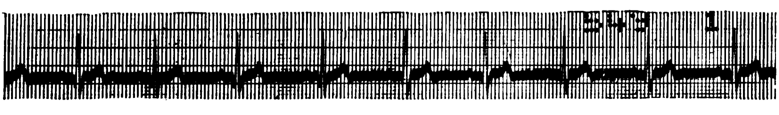


Fig. 180.—Cardiograph of electro-currents developed in the human heart.

made by the electric currents developed in the heart at each of the contractions of that organ. These currents deflect a galvanometer filament which in turn throws a shadow on a sensitive film

which is moved at a constant speed of 1 space per $\frac{1}{25}$ sec. The 10 vertical spaces equal 1 cm. and measure 1 millivolt of current. The study of the direction, time relations and magnitude of the currents developed by the heart contractions constitute modern electro-cardiography. Figure 181 shows the pressure curve of the heart pulsations direct taken by a sphygmograph fastened to the wrist or throat of the patient. The record is made on

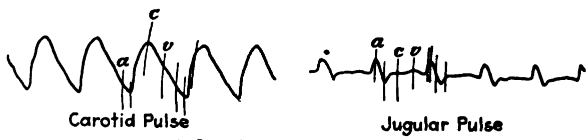


FIG. 181.

smoked paper which is afterwards fixed to prevent obliteration. The paper moves at a uniform rate which is regulated by the operator and the humps in the curve depend on the frequency of the heart pulsations.

Another graphical record of a similar kind is that made by a strainograph on the concrete ship "Faith" and shown in Fig. 182. The notches in the top line indicate the speed of the paper as they are 15 sec. apart. Ordinates represent tension and compression to the scale indicated on the left-hand margin.

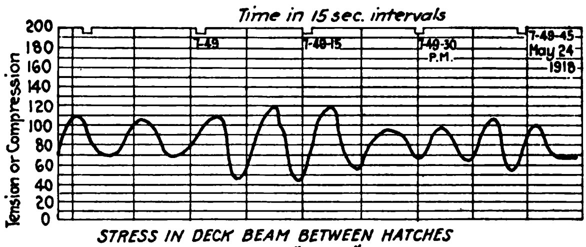


FIG. 182.

A similar record is shown in Fig. 183 which was made on a Westinghouse totalizing wattmeter. The ordinates are watts of electric current and abscissa time intervals of 10 min. each.

Records of the same kind but having a vertical scale of volts or amperes are made on graphic voltmeters and ammeters.

A record of pressure of gas is shown on the chart of Fig. 184 which has taken from a gas pressure recording meter. This

measures the actual pressures of gas passing. Below the zero line vacuum indications are recorded.

A recording instrument of especial value in railway work or in fact any line of transportation is the Wimperis accelerometer

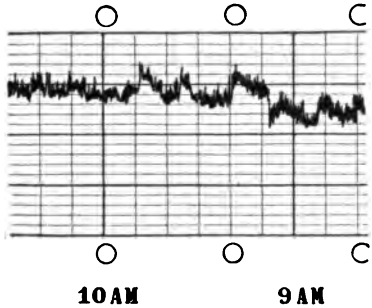


Fig. 183.—Westinghouse graphic meter record.

and equilibristat. It gives two kinds of charts, (1) one showing starting acceleration, braking and coasting as indicated in Fig. 185. This is a record made on a recording accelerometer during the time a train was stopping at a station and starting from the same station. Ordinates denote accelerations in feet per second

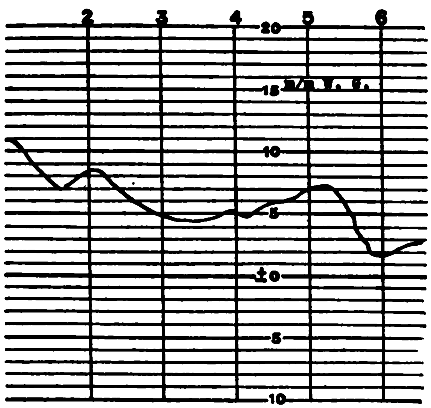
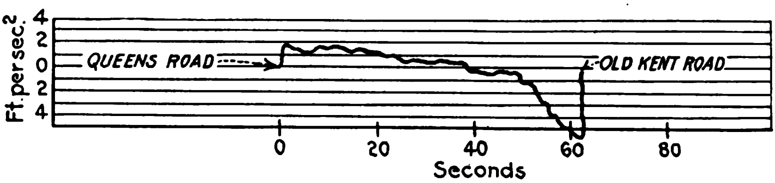


Fig. 184.—Gas pressure recording chart.

per second and abscissas are time intervals. Motion of the paper is produced by clockwork. (2) When used as an equilibristat the needle points in the direction of motion of the train or vehicle and moves according to influences tending to throw the vehicle out

of level towards either side (centrifugal force on curves, or elevation of either rail).

On straight sections of track this will be indicated on the graphical record. This is shown by Fig. 186 which is a partial equili-



ACCELERATION CURVE FOR L.B.&S.C.RY.
A.C.ELECTRIC TRAIN
FIG. 185.

bristat diagram taken from an express train of the London and South Western Railway. The upper line gives the speed in miles per hour. The line just below the arrow is mileage. The oscillation curve is given by the needle. The lowest line gives the layout of the railway, the figures being radii of curvature

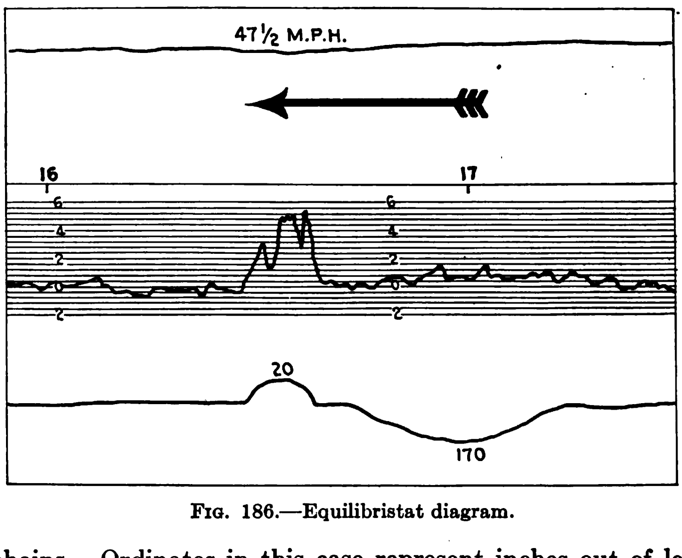


FIG. 186.—Equilibristat diagram.

in chains. Ordinates in this case represent inches out of level. In Fig. 187 is a record of acceleration of a 15-hp. touring automobile made on the Brooklands track by a recording accelerometer made especially for automobiles. The ordinates show accelerations in feet per second per second.

The Yarway blowoff meter prepares a graphic record as shown in Fig. 188 on which appear two separate records one of which is made with a short pen (line *A*) and which is magnified 10 times. The range of the short pen is 0 to 33,000 lb. per hour and the long pen from 0 to 300,000 lb. per hour as shown by the scale on chart. Different colored inks are used on the two pens and they are spaced 2 hr. apart to prevent colliding. There are two

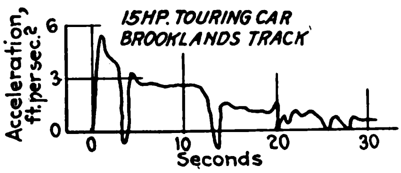


FIG. 187.—Acceleration diagram. Wimperis accelerometer.

sets of figures at the bottom, upper in black, lower in red, indicated by roman and italics respectively. Corresponding chart lines are shown at *B* and *A*. The motion of the chart is obtained from a clock. The movement of the pen is obtained from a float actuated by the water passing through the floatchamber.

Besides this type of chart there is one of a similar kind which shows two records of different kinds of conditions as shown in

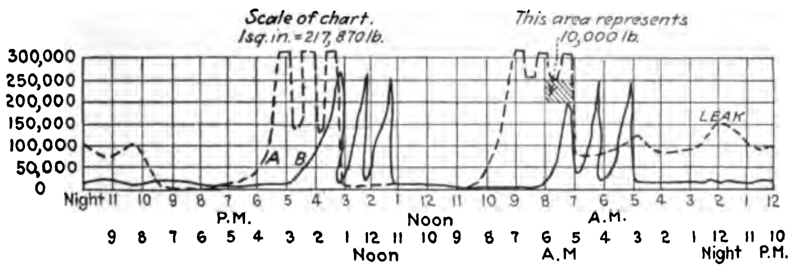


FIG. 188.

Fig. 189. The upper chart ordinates represent rate of flow of water in pounds per hour while the ordinates of the lower record indicate temperatures in degrees Fahrenheit. Such a record is advantageous from the fact that comparisons are readily made by inspection and show conditions at the same hourly periods. This chart was made on a Lea V-notch recording meter.

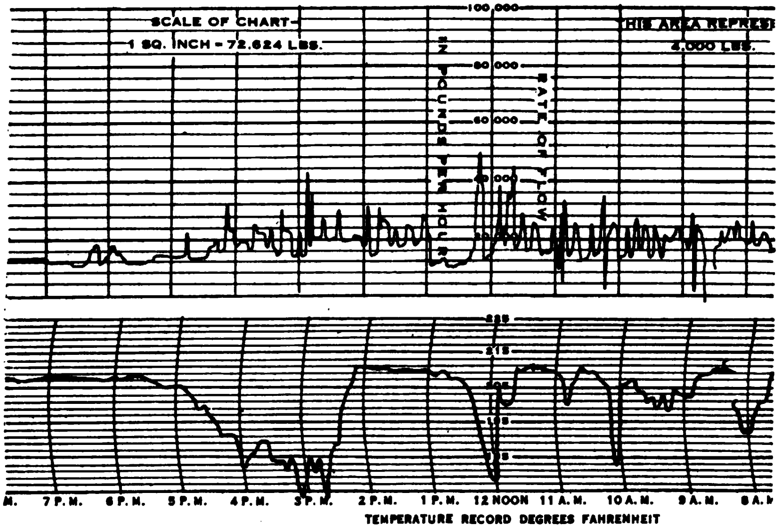


FIG. 189.—Chart from Yarway-Lea recording meter.

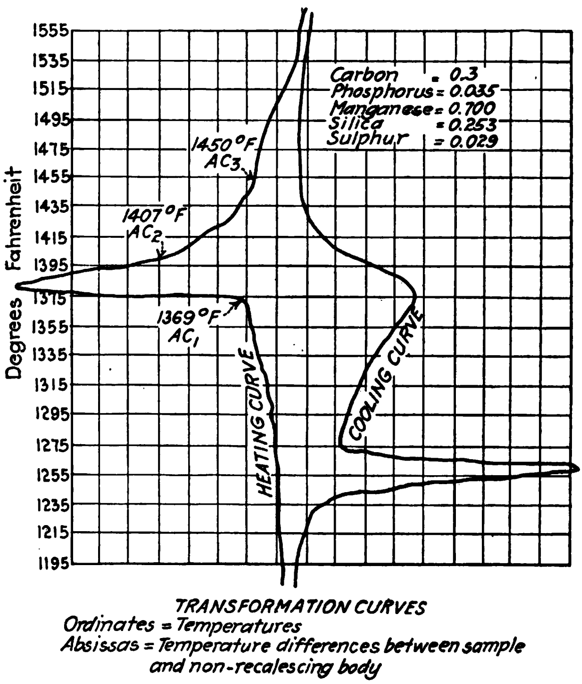
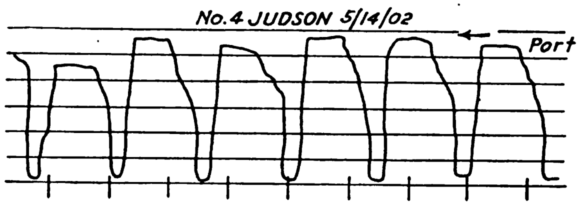


FIG. 190.—Leeds and Northrup transformation recorder curves.

Figure 190 is taken from a Leeds and Northrop recorder designed to show the transformation curves obtained when steel is heated above its critical temperature and allowed to cool. The curves are drawn by a pen whose position is controlled by



OAR LOCK PRESSURE DIAGRAM

FIG. 191.

an operator who follows the movement of two spots of light which show on a ground glass screen. Their movement comes from two reflecting galvanometers connected to a potentiometer which in turn is connected with a sample of the steel under test and to a non-recalescing body. The ordinates are temperatures

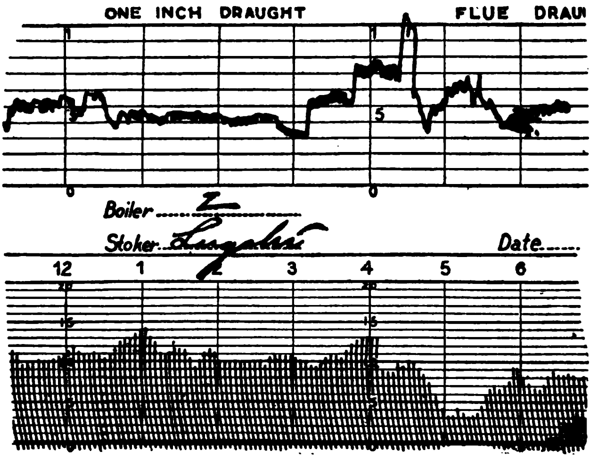


FIG. 192.—Precision combustion and draft recorder.

and the abscissas are temperature differences between the steel and the non-recalescing body.

In Fig. 191 is shown a form of recorder similar to the one shown in Fig. 180. It was designed and used by the author to record the pressure exerted by an oarsman on the oarlock of an eight-oar

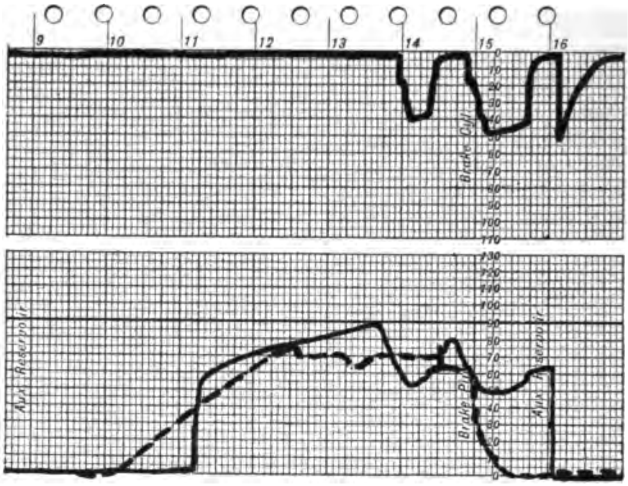
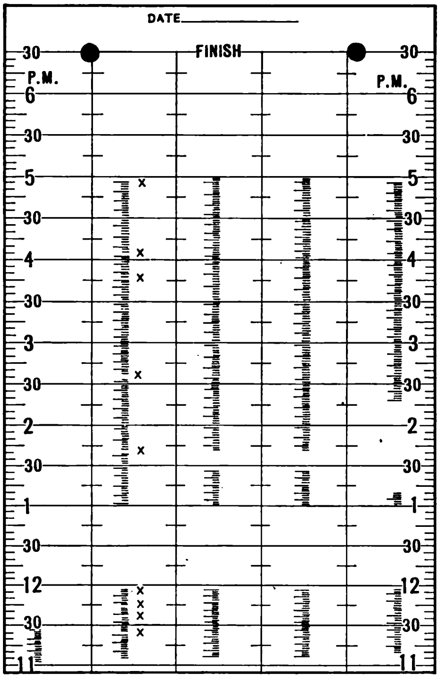


FIG. 193.—American trainagraph records of air pressures.



Productograph Record

FIG. 194.

racing shell for every stroke taken during a 4-mile row. The abscissas represent successively lengths of power stroke and recovery. Ordinates represent pressures on the oarlock at each point of the pulling stroke. The movement of the paper is obtained from the angular movement of the oarlock about a pivot.

In some cases it is advantageous to have two or more records in parallel on the same strip of paper. A sample of this kind is shown in Fig. 192, a record made by a Precision CO_2 recorder and a draft gage. The abscissas are periods of time, the ordinates

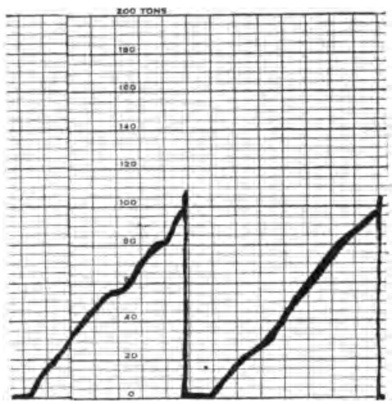


FIG. 195.—Graphic wheel press record chart for the American hydraulagraph.

representing pressures in the upper and percentages in the lower chart. Comparison can easily be made and the influence of draft on CO_2 noted.

Figure 193 shows a record of the air pressures on a train made by the American Trainagraph. Here there are three pens recording pressures in air reservoir, brake pipe and brake cylinder, ordinates representing pounds per square inch. A comparison of operations can be made by these three curves as they are drawn at the same time and from closely connected pipes.

In Fig. 194 the record from a Productograph is shown. This has four records but as many as 20 pens are used in a single recording instrument. This records motions or operations of machines, the paper moving by clockwork and the pens by electrical current

In Fig. 195 is a diagram from an American Hydraulagraph. This is a simple succession of diagrams whose ordinates denote

tons pressure, the abscissas representing any distances whatever but long enough to move one diagram away from the space to be occupied by the one to follow.

Figure 196 is a record of the pressure in a steel furnace made on

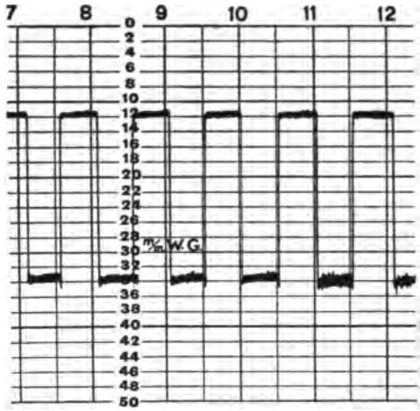


FIG. 196.—Bacharach blast furnace pressure record.

a Bacharach pressure recorder. The ordinates give pressures in millimeters of water. The advance of the paper ribbon is by means of clockwork.

A graphic record of draft in furnaces is shown in Fig. 197. The records here are from a hydro-differential draft gage and

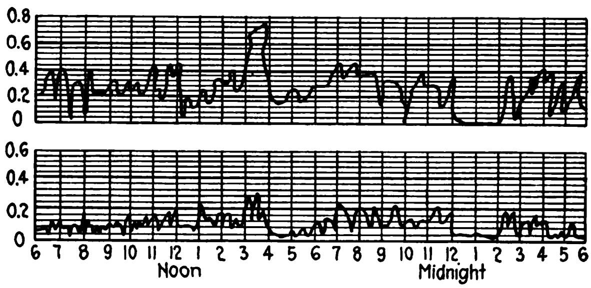


FIG. 197.

from a combustion chamber gage and represent tenths of inches of mercury. Movement of the paper is obtained from a clock. There are several types of machines which draw a record on paper having rectilinear coordinates the record being used to

check the observations of the operator. A tensile-testing machine is an example of this.

A diagram from a Riehle testing machine is shown in Fig. 198.

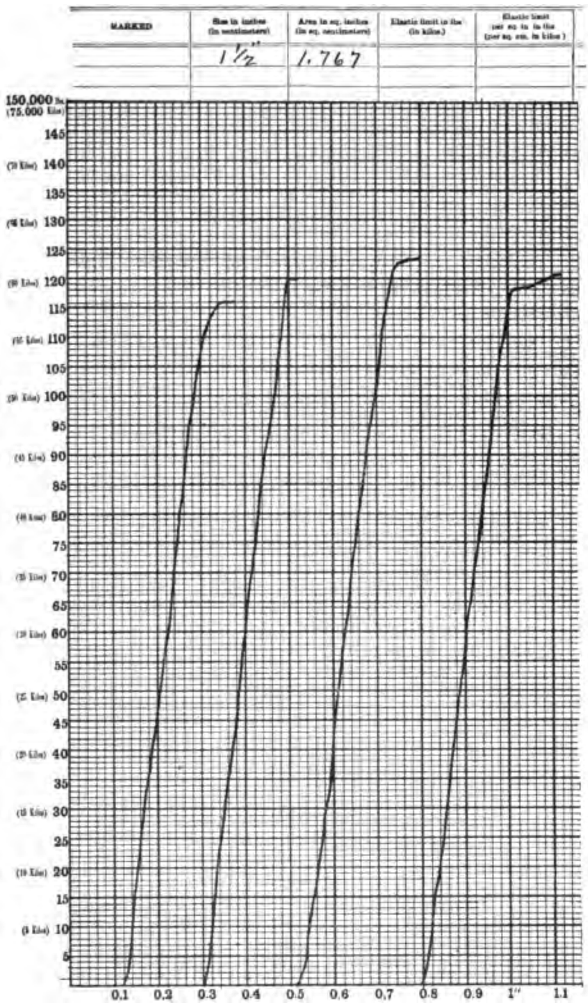


FIG. 198.—Strain diagram from a Riehle testing machine.

The record shows the elongation of the test specimen by abscissas while ordinates represent the load applied. This is used for testing metals. The strain is magnified 50 times. Other diagrams in which revolutions are used for abscissas and also torque are shown

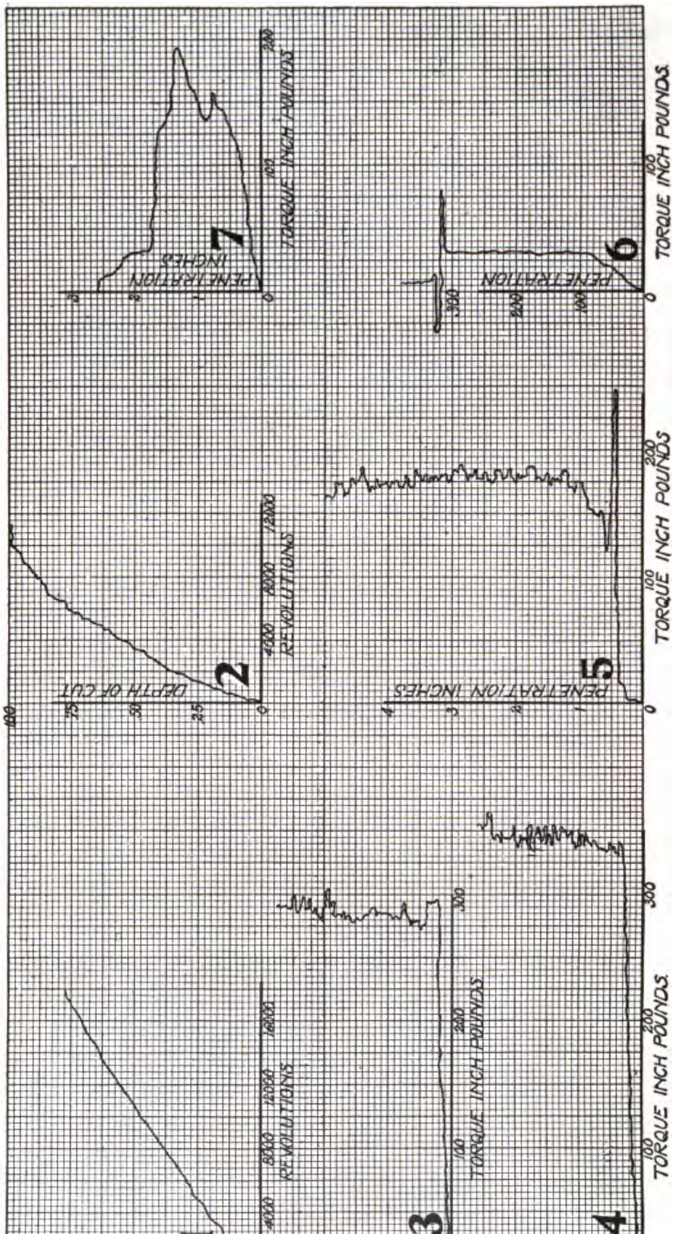


FIG. 199.—Diagrams of tests made on Olsen efficiency testing machine.

in Fig. 199. All of these diagrams are actual curves made by the Olsen Universal Efficiency Testing Machine under working conditions. The scales used are indicated on the axis. A description of each diagram follows.

No. 1. Curve No. 1 is that of one side of a file tested.

In this test a standard tool-steel test bar is used and the relation between material filed and number of revolutions recorded with the file under definite standard pressure and operating under standard cutting speed.

No. 2. Curve No. 2 is that of a hack-saw blade test.

In this test, as in the file test, a standard steel bar is used, showing relation between depth of cut and revolutions recorded under standard pressure and cutting speed.

No. 3. Curve No. 3 represents the test on a ¾-in. high-speed drill.

In this test 0.30 carbon steel shafting is used as standard material, with a drill speed of 360 r.p.m. and feed of 0.01 in. per revolution. The pressure at the point of the drill was noted at 1,100 lb.

No. 4. Curve No. 4 represents the test on a ¾-in. carbon steel drill.

The conditions of the test, excepting for the speed, was the same as in the case of the high-speed drill. The speed in this case being only 90 r.p.m., while the pressure at point of drill was 1,350 lb.

Comparing No. 3 and 4. From the curves and data reported it can readily be seen that the high-speed drill operates under less pressure and less torque than the carbon drill, and at the same time doing four times the amount of work. The power factor is thus many times less using the high-speed drill and the strain on the machine correspondingly less.

No. 5. Curve No. 5 is of a machine die and in this test a rod is run through the die under standard conditions and relation between torque and penetration recorded.

No. 6. Curve No. 6 is the test of a 27/64-in. carbon drill drilling standard material at a speed of 370 r.p.m. and under a gravity of 200 lb.

The relation between torque and penetration is recorded, and we wish to call special attention to the heavy torque required for drill to penetrate the material. This added torque often breaks drills and proper grinding will largely remove the trouble.

No. 7. Curve No. 7 is the test of a ½-in. nut tap in tapping hole bored as shown by curve No. 6, running at speed of 90 r.p.m. The relation between torque and penetration is recorded and the area of diagram represents the work of tapping.

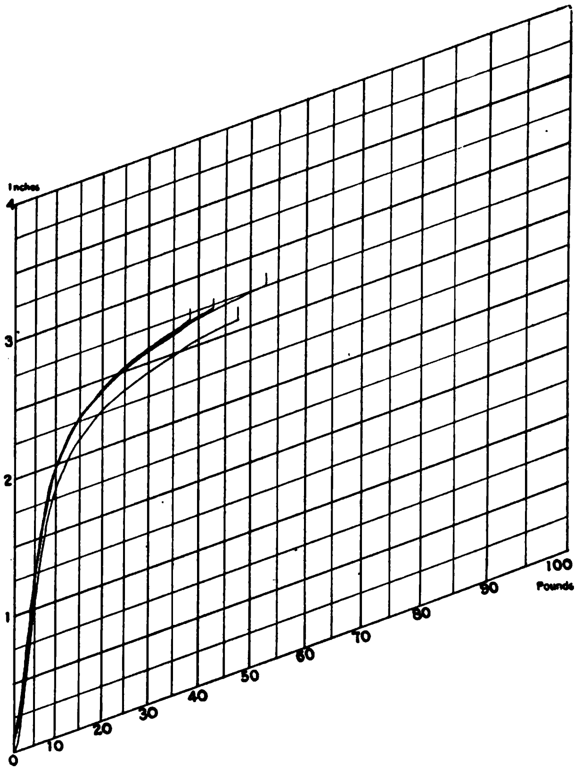


Fig. 200.

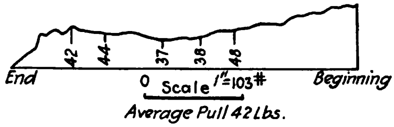


Fig. 200A.

In Fig. 200 are shown the curves made on a textile testing machine recording attachment while four different strands of yarn were being broken. Ordinates represent stretch of the yarn and abscissas represent the pull which produces the stretch.

DYNAMOMETER TESTS OF TRACTORS AND PLOWS

REMARKS: 8–16 Int'l. Tractor, at Hinsdale farm. SHEET No. 2 A
10" Wheels-extension angle lugs-right hand wheel in furrow. TEST No. 22
To determine d.b.hp.– and d.b.p. as follows:

Section Number	"A" Draw-bar area	"B" Length	"C" Velocity M.p.h.	"D" D.b.p.	"E" Db.hp.	"F" Average Depth area	"G" Plowing depth	"H" Dbp in depth
20	4.50	3.03"	1.72	1485	6.82	10.75	9.10	163.
21	3.38	1.99	1.13	1699	9.02	7.66	9.70	175.
22	1.72	1.13	0.64	1522	2.61	3.76	3.66	176.
23	2.38	1.64	0.93	1451	3.61	5.45	8.64	168.

"A" Draw bar area: Measured by hand with a planimeter for each 30 sec. division.
"B" Length: Distance of paper travel in 30 sec. scaled.
"C" Velocity in m.p.h. = length time 25 divided by 44.
"D" Draw bar pull(d.b.p.) = "A" + "B" × 1000(50# spring gives 1000# per inch)
"E" Draw bar h.p.(d.b.hp.) = "C" × "D" + 375.
"F" Average depth area = (DB + DR) divided by 2.
"G" Plowing depth – ("F" + "B") × 2 + 2(depth readings are reduced in the ratio of 2 to 1. Plows set 2" deep when pencils record zero on chart.
"H" Draw bar pull per inch depth = "D" + "G."

All results obtained by comptometer, tables or logarithmic charts, except 'A" and 'B'

DYNAMOMETER TESTS OF TRACTORS AND PLOWS

REMARKS: 8–16 Int'l tractor at Hinsdale farm. Wheat SHEET No. 2 B
Stubble—dry—new standard extension on lug on 10" wheel 40" diameter. TEST No. 22

Section Number	Furrow wheel			Land wheel		
	'J" Revolutions and paper travel	'K" Ground travel	'L" Per cent slip	'M" Revolutions and paper travel	'N" Ground travel	'P" Per cent slip
20	10–2.95"	73.75'	29.6	8–2.85"	71.25'	14.9
21	9–2.13"	53.25'	43.5	7–2.18"	54.50'	25.6
22	7–1.07"	26.75'	63.5	4– .99"	24.74'	40.9
23	12–1.72"	43.00'	65.8	7–1.75"	43.75'	40.3
24	10–1.55"	38.75'	63.0	7–1.56"	39.00'	46.8
25	8–1.21"	30.25'	63.9	5–1.31"	32.75'	37.4
26	7–1.81"	45.25'	38.3	7–2.03"	50.75'	30.8

"J" Number of revolutions made in approximate 3 sec. Exact distance of paper travel measured for the number of revolutions made.
"K" Paper travel measured times 25.
"L" 100(K divided by peripheral travel of drive wheel)
"M"—'N"—'P" corresponding valves for land wheel.

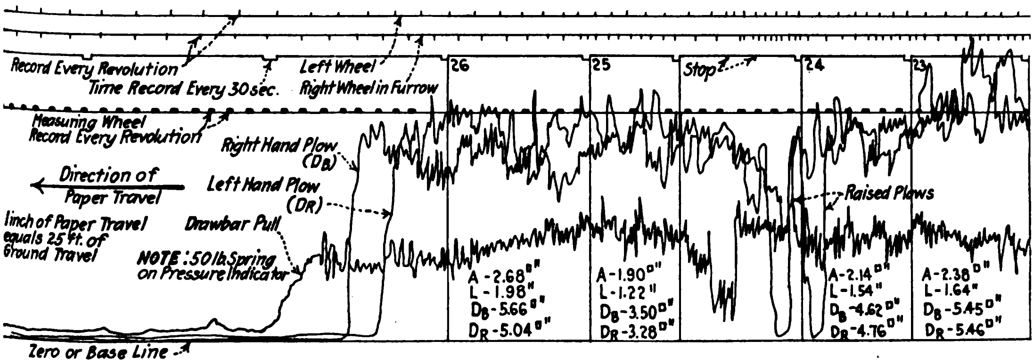


FIG. 201.

Figure 200A is a dynamometer record of drawbar pull necessary to move an automobile on a level floor. The pencil is actuated by a Tabor gas engine indicator and the paper is moved by a clock. Ordinates represent pounds pull. A record of drawbar pull on a much more comprehensive scale is shown in Fig. 201. This is a record of drawbar pull of tractor pulling two plows and the pull exerted on each of the plows as well. A description of the various phenomena and conditions of the test will be found in the tables which accompany the record.

One of the most common recording instruments is the steam engine indicator. This draws a diagram which shows the pressure in the cylinder of a steam engine at every point in the stroke

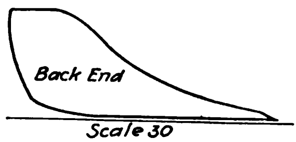


FIG. 202.—Steam engine indicator diagram.

of the piston. A sample of the diagram drawn is shown in Fig. 202. Abscissas denote positions of the piston along the stroke and ordinates represent pressures in the cylinder at each of these positions. The paper is held on the surface of a cylinder which is oscillated by being connected with the moving piston. A pencil point actuated by the pressure of steam in the engine cylinder is pressed against the paper and draws the indicator card. The scale to be used in measuring ordinates depends on the spring used in the indicator. It is usually denoted on the card as "Scale 30" "Scale 50" etc. in Fig. 202.

A similar diagram can be made from the cylinder of an internal combustion engine but the line of pressures is traced by a beam of light instead of a pencil point and the paper is sensitized instead of plain.

There are two types of diagrams taken from an internal combustion engine and shown in Fig. 203. The pressure volume card is similar to the steam engine card of Fig. 202. The pressure-time card is useful in studying fuel characteristics. The beam of light which describes the pressure curve has a compound movement and the paper does not move as on steam engine indicators.

In the class of graphic records illustrated in Fig. 167*e* is found the record of Fig. 204 made by a recording pyrometer of the Taylor Instrument Co. The ordinates are of a non-uniform scale and represent temperatures from 0 to 2,500°F. The curve is composed of a series of dots. The paper is moved by clock-

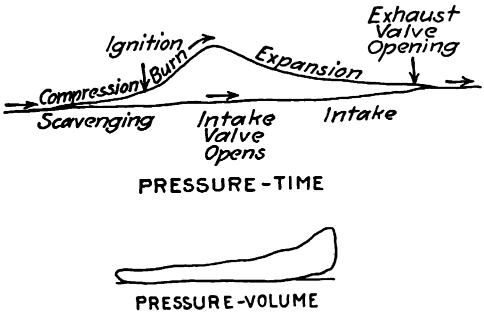


Fig. 203.—Internal combustion engine diagrams.

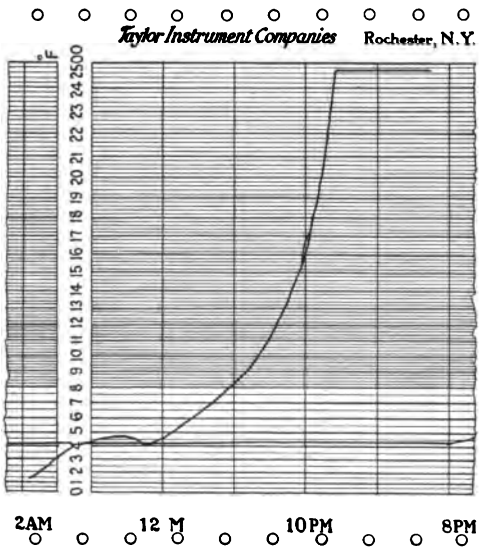


Fig. 204.—Taylor recording pyrometer record.

work. Figure 205 is a sample chart made on a Bacharach volume recorder for measuring volume of gas or air by the Pitot tube principle. This ribbon is 8 in. wide and the divisions are logarithmic. The motion of paper is obtained from clockwork, the time divisions being uniform.

The ribbon graphical records so far mentioned have been made on paper having straight line ordinates. There are many diagrams which are made with a pen which moves in a circular arc and records on paper having circular ordinates. These diagrams

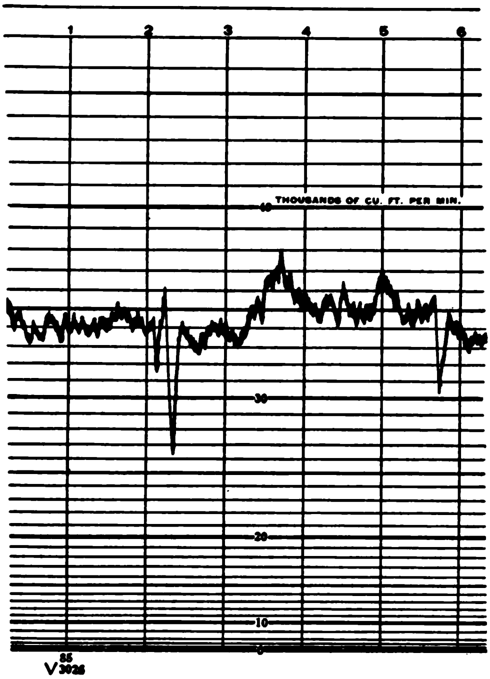


FIG. 205.—Bacharach volume recorder for gas or air.

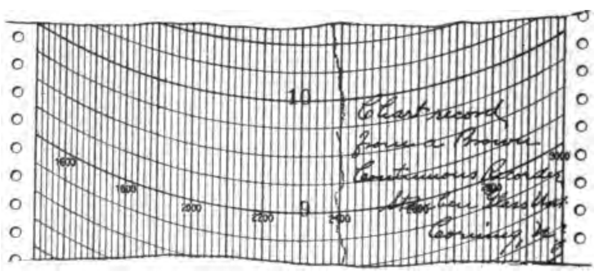


FIG. 206.—Brown recording pyrometer record.

belong in the class shown in Fig. 167*f* and *g*. A record of this type is shown in Fig. 206.

This is a recording pyrometer record made by a series of dots on a paper ribbon moved by clockwork. The ordinates represent

degrees Fahrenheit. Records from recording barometers are shown in Figs. 207 and 208. These charts are made to record for a week without change of paper. Ordinates are inches of

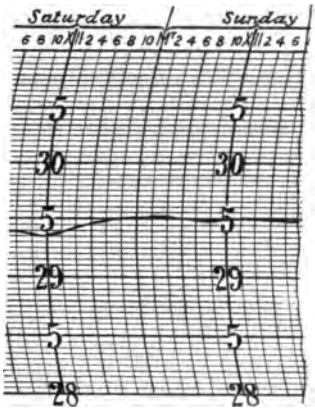


Fig. 207.

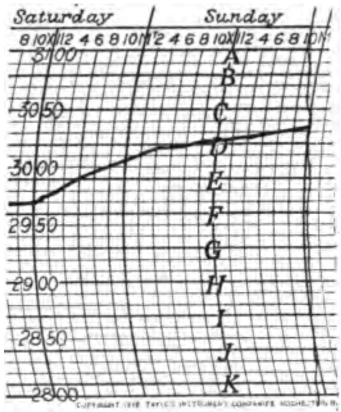


Fig. 208.

Recording barometer records.

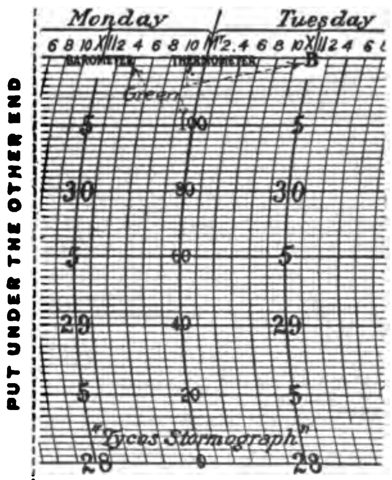


Fig. 209.—Recording barometer and thermometer records combined.

mercury and abscissa are time intervals. Measurements of ordinates can be more accurately made in 207 than on 208 but the record is equally good on both.

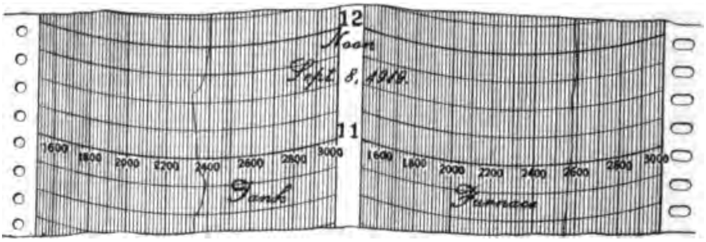


FIG. 210.—Double record from duplex pyrometer.

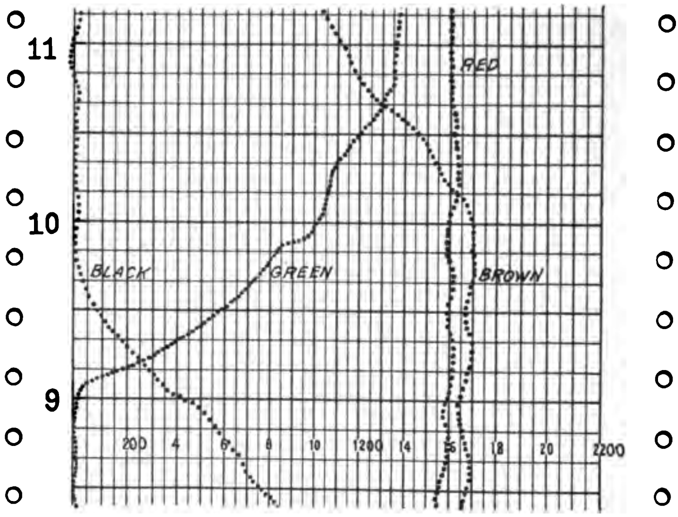


FIG. 211.—Englehard multiple pyrometer record.

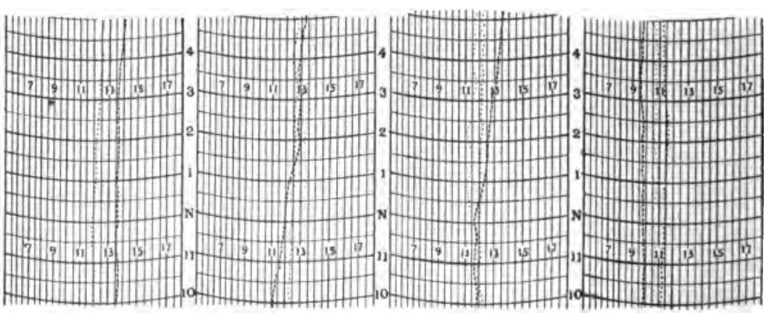


FIG. 212.—A four-record chart from a Thwing recorder.

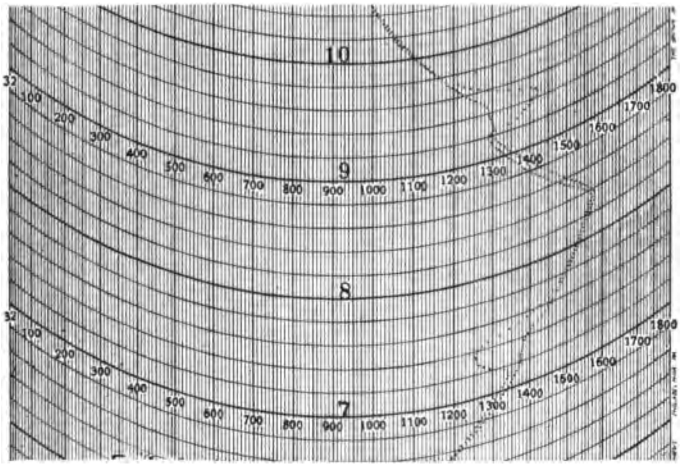


FIG. 213.—Critical temperature chart.

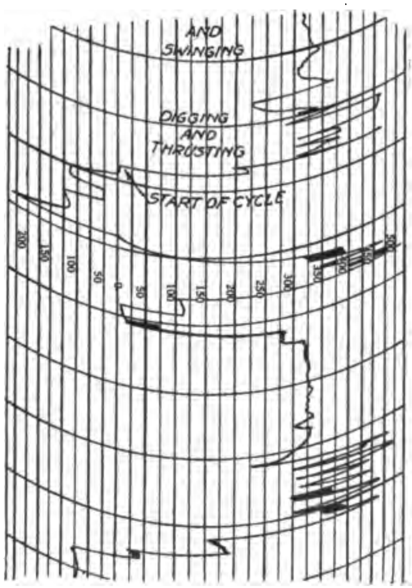


FIG. 214.—Esterline graphic recording power factor meter chart.

Figure 209 is a chart used for two records one of temperatures, one of barometer heights. There are two scales for ordinates, the time element remaining the same. This is from the Stormograph of the Taylor Instrument Co.

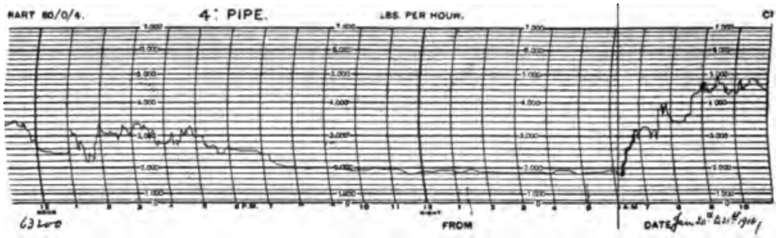


FIG. 215.—Curnon meter record of steam delivered.

A record from a duplex pyrometer is shown in Fig. 210. One line gives tank temperatures the other those in a furnace. There are two separate ordinate scales, although it is possible to run several records on one ribbon with one scale only. The lines in that case would be made in different colors. These are made on thin paper from which blue prints can easily be made.

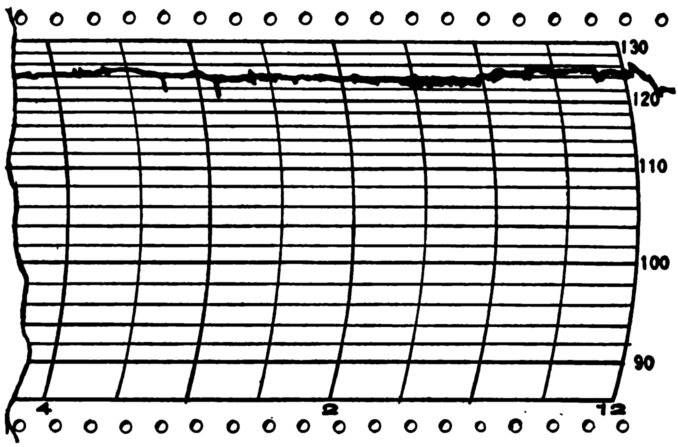


FIG. 216.—Chart from Westinghouse graphic recording voltmeter.

A recording pyrometer record made on a recorder with four pens is shown in Fig. 211. There are four colors of ink which avoids confusion if the lines happen to cross. Temperatures run from 0 to 2,100°. The paper travels by clock mechanism, the holes in the edges of the paper fitting over teeth in a driving

drum which eliminates any chance of slipping while passing throught he instrument. This is made on an *Englehard* recorder which can be arranged to trace 12 different records if required.

A similar pyrometer record is made by the Thwing recorder, the principal difference being that the lines of Fig. 211 are colored to distinguish them while the lines themselves of the Thwing record are composed of different kinds of dots and spacings.

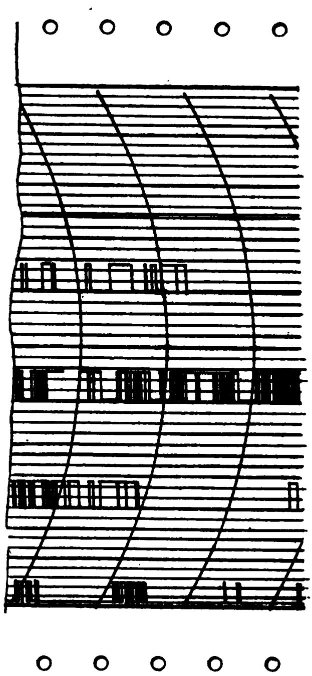


FIG. 217.—Chart from Esterline graphic time recorder.

A four-record chart is shown in Fig. 212. As many as 12 records can be made on a single chart. The paper is moved by clockwork and is long enough to last 24 hr. without change.

Figure 213 is a graphical record of the behavior of steel when heated above its critical temperature and allowed to cool. The two lines represent the temperature of the steel specimen and the recalescent standard. This record can be compared with the one shown in Fig. 190 made with straight line ordinates.

In Fig. 214 is shown a graphical record of the type of chart noted in Fig. 167*g*, having curved non-uniform ordinates. This

was made on an Esterline graphic recording power-factor meter. The ruled portion is 4½ in. wide. The speed of the paper through the meter can be varied from ¾ to 12 in. per hour, although rapid fluctuations can be provided for by minute chart speeds varying from ¾ to 6 in. per minute. The standard speed is 3 in. per hour.

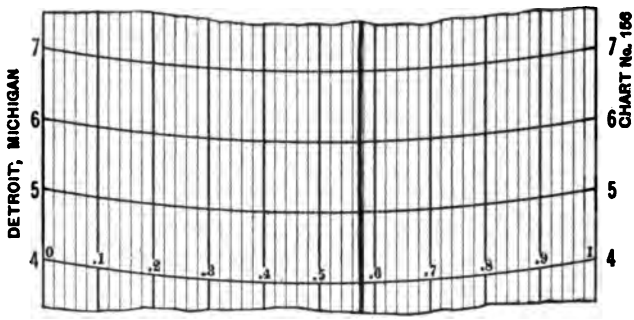


FIG. 218.—Chart from Precision Instrument Co. gravitometer.

A similar type of chart is one from a Curnon steam meter, the steam measurement being based on the Pitot tube method. Ordinates represent pounds of steam per hour. This is shown in Fig. 215. The ordinates are non-uniform scale

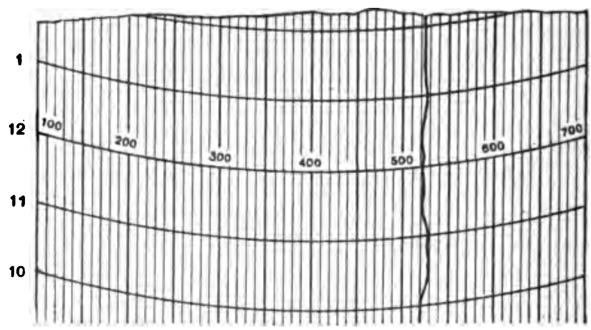


FIG. 219.—Colorograph chart of B.t.u. content in gas.

A type of chart having curved ordinates and unequal spacing on the vertical scale is shown in Fig. 216. This was made on a Westinghouse graphic recording voltmeter. The time intervals are 15 min. each and motion of the chart is obtained from clock-work.

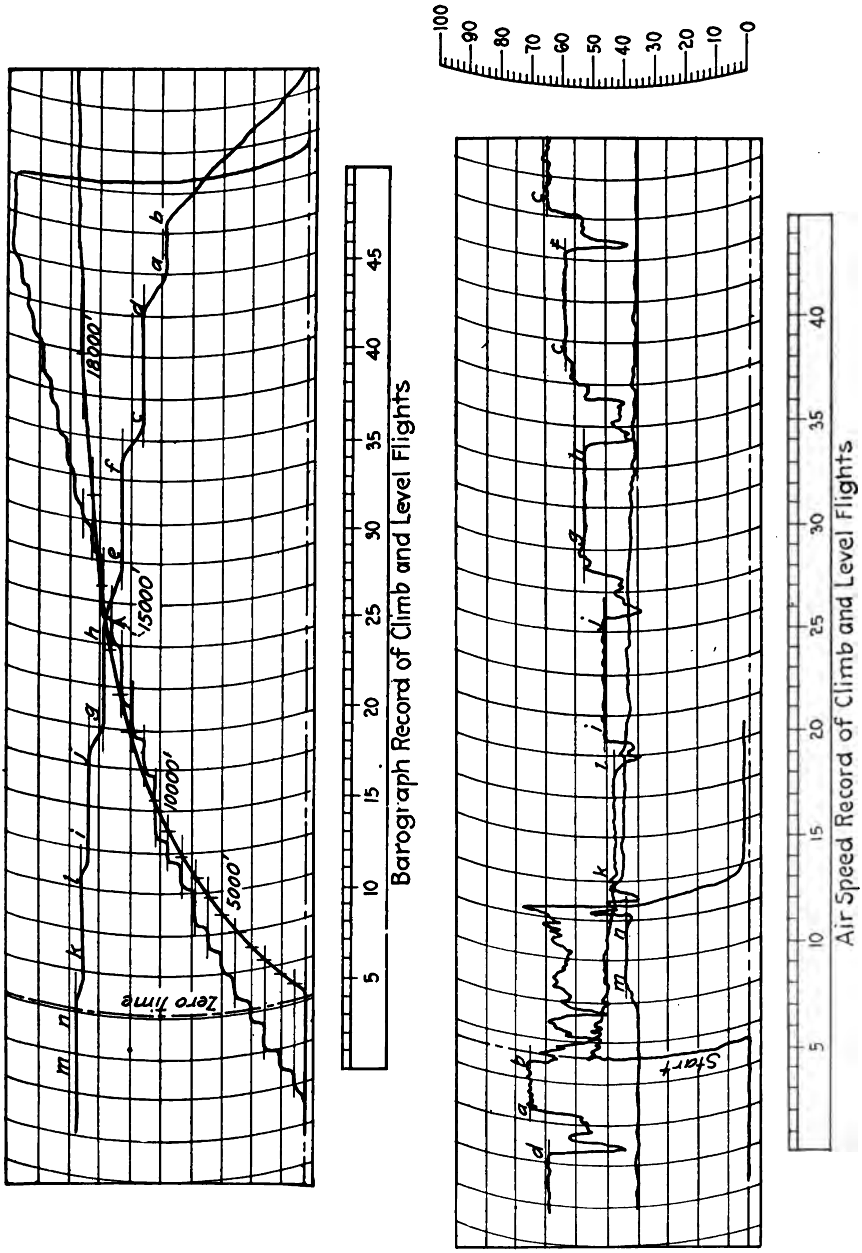


FIG. 220.—Toussaint-Le Pere air speed and barograph record.

A chart showing amperes instead of volts but differing in no other respect is the product of an ammeter.

In Fig. 217 is shown a diagram made by an Esterline graphic time recorder. This indicates only when certain machinery is put in motion. Five different machines are indicated here, the upper line being continuous which shows no movement of that machine. These records have a time value only as ordinates are of no value for measuring quantities. The paper can be moved through the recording instrument at a speed suitable for the records desired.

In Fig. 218 is a chart showing the density of Newark Public Service Gas referred to air as unity, made on a Precision Instrument Co. Gravitometer. In Fig. 219 is shown a chart from a Colorgraph of the same gas. This gives the B.t.u. content in Newark Public Service Gas. Ordinates are curved in both these diagrams but the divisions of the vertical scale are equal.

The speed of airplanes is obtained by an airspeed recorder. The one at present used in government work is the Toussaint-Le Pere. It works on the Pitot-Venturi system and the pen records on a continuous paper strip. The speed record is usually accompanied by a barograph record.

Figure 220 is a record made with a Toussaint-Le Pere air speed recorder. The paper is moved by clockwork, the horizontal scale reading to minutes.

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